

THE IMPACT OF ARCHITECTURAL TECHNOLOGY ON
ARCHITECTURAL ART THROUGH DETAIL DESIGN
— WITH SHANGHAI CITY AFTER THE CHINESE ECONOMIC REFORM
AS EXAMPLE

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By
YINAN HOU

DArch Committee:

PU MIAO
JUAN CHEN
WILLIAN CHAPMAN

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Abstract

Architecture is not only an art, but also a technology. Architectural technology involves many aspects of building construction such as construction crafts, structural design and materials applications. Since the Chinese economic reform, new materials, technique, structure and standards are continuously emerging within China, and undoubtedly have a significant impact on the development of architecture we see today. These impacts not only affect the construction process but, also subtly influence architecture as an art, specifically in detail design. As the relationship between architectural art and technology, the details are often the first to be shaped by the changes in architectural technology.

Accordingly, this dissertation will introduce the impact of architectural technology on detail design:

First, the changes of architectural technology affecting traditional materials and craft indeed creates restriction on architectural detail in terms of material authenticity and structure logicity. This results in the rationalism that architects gradually feel a lack of control in detail design. Secondly, although the development of architectural technology has brought forth new ways to demonstrate architecture as an art, architectural detail design tends to be more

homogeneous as the result of stricter laws and regulations, higher labor cost, and construction industrialization to name a few. The improvement of architectural technology has negatively affected the diversity of detail in architecture to certain degrees. Meantime, the facades of buildings tend to be flat as a result of the enactment of building energy-saving regulations. Thus, the surface design is gradually prevailing. Finally, the development of architectural technology creates an increasing number of traditional details with practical functions that are no longer needed. This causes there to be gradually less expression of detail on buildings, and encourages a minimalist design that fits the trend of homogenization and surface design in architecture.

Accordingly, three conclusions below of this dissertation are drawn:

1. Based on rationalism, there is less opportunity for architectural detail design, due to restrictions that arise in the pursuit of architectural authenticity.
2. Contemporary architects are paying more attention to the aesthetic expression of surface design. The link between the building's internal construction and external form is being disrupted.
3. Surface design and minimalism will become more popular building styles.

CHAPTER 1.INTRODUCTION

1.1 Objectives

In the 'Seven Arts', which indicates the traditional subdivision of the Arts that is universally acknowledged, architecture is included. However, architecture is very different from the other types of art. For instance, the creator of the artwork such as canvas to painting, scenery or costumes to drama is somewhat, if not completely, a decisive influence on the expression. However, for architecture, the situation becomes different. In architecture, the construction of the carrier is what the artwork wants to present. In other terms, the material and technology used in buildings construction have a decisive significance for architecture. Kenneth Frampton once wrote, “*the built is first and foremost a construction and only later an abstract discourse based on surface, volume, and plan.*”¹

In the document, *Aesthetics and Technology in Building*, an Italian engineer and architect, Pier Luigi Nervi, explains that all the world-famous, excellent architecture buildings, in which architectural technology and art are perfectly

¹ Kenneth Frampton, *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture* (Cambridge: MIT Press, 1995), 2.

combined, are a form of "correct building", and they all have the characteristics of "correctness". Nervi defines correctness as, "good technology", or the rational use of the architectural technology, as the foundation for the building to achieve the desired artistic effect. For example, a gothic church's internal space often gives people a towering and magnificent feeling, however, this feeling doesn't appear out of thin air. Its appearance is often accompanied by the emergence of the user's awareness of the building material - in this case, stone is fully utilized to ensure the maximum stability of the building. Since stone is a kind of building material that people often come into contact with, this awareness is often subconscious, however, can generate the sense of security. Under the premise of this sense of security, people can further enjoy the beauty from the building. Accordingly, the author argues that the importance in "building correctly" should "*be understood in relation to the technical process and materials used in a given time and place.*"¹ For further understanding, utilizing reasonable technology is a base of the "correct building".

However, reasonable technology cannot be the only factor regarded as to how the outstanding buildings in history became so. In fact, from a long historical

¹ Pier Luigi Nervi, *Aesthetics and Technology in Building* (Cambridge: Harvard University Press, 1965), 8.

perspective, compared with architectural style, structural technology developed slower. The impressions of outstanding buildings in different historical periods, even in the same period, can be hugely different. The significance of this is that in addition to the factor of architectural technology, architectural art, which depends more on the subjective factors such as the ability, experience and aesthetic standard of the architect, plays an important role in what Pier Luigi Nervi described as, “correctness”. For example, in the ancient Greek temple, its beam-column structure is the result of a simple mechanical principle, far from scientific and economic. Based on these primitive construction techniques, the ancient craftsmen devoted their passion for beauty on the pediment, frieze, chapter, and plinth to names a few, which allowed primitive architectural technology show endless aesthetics. Therefore, what Nervi called “building correctly” is composed of the “correct” architectural technology and art, which is created by the architect relying on his own superb artistic accomplishments. In short, in one building, architectural technology and architectural art can be interdependent, complementary and inseparable to each other.

However, is the relationship between architectural technology and art established only at the level of an entire building? Nervi, who believed that technology is the base of architecture, claims that “*only for very small*

*dimensions does one have practically complete freedom.”*¹ If there are any so-called restrictions, it is nothing but out of consideration for the aesthetics. He wrote, *“it would be ridiculous, for instance, to worry about shaping a window frame according to static concept.”*² Nervi further conveys the point that architectural technology need only be correct on the building structure level or higher. On the lower level, such as architectural detail, architects are free to design. Unfortunately, plenty people agree with this view. For example, in many architectural books involving the relationship between architectural technology and art, architectural technology mentioned actually refers only to structure technique. It seems to also be a common problem among many junior architects. When doing the design, these architects always pay much attention to the structural technology, which relates to the shape of the building. But for the details, they are only concerned with aesthetic factors, not technical ones. Therefore, the question is posed, is the reality really what Nervi said, that architects can freely design architectural details without consideration of architectural technology?

“What is ‘architectural details design’? In my opinion, it is the operation of

¹ Nervi, *Aesthetics and Technology in Building*, 187.

² Ibid.

*morphology and technology by the practice of craft in the construction process.”*¹ As Professor Mo Tianwei at Tongji University in China wrote, he argues that architectural detail is partly derived from architectural technology. In the article, *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*, Kenneth Frampton wrote: “*Detailing should never be regarded as an insignificant technical means by which the work happens to be realized. The full tectonic potential of any building stems from its capacity to articulate both the poetic and the cognitive aspects of its substance.*”² This means that the tectonic, or to say the “correct” architectural technology should be the predominate formation of architectural details. Thus, the design of architectural details has to be restricted by architectural technology. The evolution of windows is a clear example. In early medieval European castles, partly because glass had been rarely used for windows and partly because the weight of the building was entirely held by the stone walls, window openings were rather narrow to avoid reduction in load-bearing capacity of walls and to prevent rainwater from falling into rooms. Along with the advent of the glass window, the interior space of the

¹ Chen Juan 陈鏊, *Jianzhu Xibu Sheji* 建筑细部设计 [Architectural Detail Design] (Shanghai: Tongji University Press, 2008), ii.

² Frampton, *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*, 26.

building was entirely closed without a reduction in natural lighting. Thereafter, given technological advancement, the size of the glass window gradually became larger. Up to modern times, the appearance of the reinforced concrete frame structure system makes windows in replacement of walls possible. Even with curtain wall technology, windows can replace walls and provide users with a maximum outdoor view. As described above, there is no detail that could not be restricted by architectural technology. Architectural technology is like a canvas, in that whatever its size, the architects have to paint “details” on this canvas without going beyond the edge. Therefore, it may not be as Nervi wrote in that except the consideration for the aesthetics, the architects “have practically complete freedom” to design architectural details.

Architectural details are passively restricted by technology, but can actively express style. In fact, detail in architecture is one of the main sources of architectural style. For instance, when it comes to classical style, what we often think of is a typical classical detail such as, a chapter, colonnade, and pediment. When it comes to Chinese traditional style, we may think of a bracket, big roof, lattice window and so on. Even today under the rule of modernist architecture, which follows Adolf Loos’ creed, that “ornament is a crime,” the content of many books of Architectural history is mainly about details. Actually, architectural style originated in the design details. Every

building component was initially a response to a functional requirement. Then, because of the necessity for beauty, people continued to modify this component, until it was slowly changed from its original appearance. When these components with new appearances come together, a new architectural style was created. Tadao Ando once wrote, “*Thus to me, the detail is an element which achieves the physical composition of the architecture, but at the same time, it is a generator of an image of architecture.*”¹ Thus, architectural detail embodies a style in architecture, and is where the expression of architectural art was formed.

If details in architecture are restricted by architectural technology, and are the main sources of architectural art, it can be concluded that architectural technology is bound to have an impact on architectural art through the design details. This is a theoretical conclusion, which is seldom mentioned in practice. Because the details are rarely the entry point for a building design, technology is often seen as a precondition for which detail in design has to comply with. Hence this dissertation aims to concretely study how architectural technology impacts detail design, and how this impact is embodied in architectural art.

¹ Kenneth Frampton, *Modern Architecture: A Critical History*, 3th ed. (New York: Thames and Hudson), 325.

1.2 Spatial and Temporal Scope of the Research

In the history of building by humans, in different periods and regions architectural technology has undergone numerous changes. Each adaptation had different effects on the evolution of architectural art. Due to the length limitation, the research of this doctoral dissertation analysis for history of the change of architectural technology is based on one period and one location. The author's study focus on the city of Shanghai after the Chinese economic reform.

1.2.1 Temporal Scope

Before the Chinese economic reform¹, due to the long-term domestic unrest and the blockade of foreign technology, the development of architectural technology in China had appeared to be stopped, or maintained at a relatively backward state. In the article, *The significant development of China's building construction technology in 60 Years since the Foundation of People's Republic of China*, the author Yang Sixin wrote: “*From the beginning of the*

¹ The Chinese Economic Reform refers to the program of economic reforms termed "Socialism with Chinese characteristics" in the People's Republic of China (PRC) that was started in December 1978 by reformists within the Communist Party of China, led by Deng Xiaoping. (Source: “Chinese Economic Reform,” Wikipedia, https://en.wikipedia.org/wiki/Chinese_economic_reform.)

1950s until the mid-1970s, except in the ‘ten big constructions’ for the 10th National Day celebration, the pace of development of the construction industry in our country was not ideal, especially during the 1960s to the 1970s.” He recalled that before the Chinese economic reform, there was a usual, relatively “primitive” scene on the construction sites. Materials handling was still managed by trolley, sometimes even by the shoulder pole. The construction was so backward, the architectural technology was difficult to develop as a matter of course. Take glass clad technology as an example, in 1910 the glass curtain wall was already being used in the Bauhaus building designed by Walter Gropius. In 1958, the outer envelope of the Seagram Building was totally composed of glass curtain walls. However, in China the earliest appearance of glass clad technology was in the Canton Trade Fair complex which is completed in 1981, and the glass curtain wall was not used until the Great wall Sheraton Beijing Hotel completed in 1984.

Since the Chinese economic reform, China’s construction industry has developed rapidly. In 2014, China’s total amount of construction area was 10.46 billion square meters, accounting for more than half of the world’s total building area. The amount of cement used in one year’s time in China, is three times more than that in the United States. The rapid development of the construction industry will inevitably promote the progress of architectural

technology. Today, China has become a test field of advanced construction technology. For example, in China's National Swimming Center, the design of the outer walls is based on the Weaire–Phelan structure, which as an innovative structural form that was used for the first time in the world. Its exterior cladding made of 4,000 ETFE bubbles is the world's largest and most complicated membrane system in one single building project. Without question, China remains in a leading position in architectural technology. After the Chinese economic reform, since the late 1980s, China's architectural technology experienced a rapid development process from the primitive, to the advanced. The period from the Chinese economic reform until today, will be used as the temporal scope of this study.

1.2.2 Spatial Scope

Before the port opening in 1843, Shanghai was a small town near the Huangpu River. Due to its convenient water transport location, its economy became well developed, and therefore the construction activities were more far more active than in surrounding provinces or cities. After 1842, the year of the Shanghai port-opening, Britain, the United States and France established concessions in the north of Shanghai, respectively. After that, a large number of Western-style buildings were built in these concessions, and introduced

western architectural technology to China. For example, the western-style red brick and masonry-timber structures were built in Shanghai, whereas the traditional Chinese brick and timber beam-column structure was the local style of building. Because of jurisdiction, western colonists also established building regulations in their respective concessions. At first, most of these building regulations were modeled after the relevant codes promulgated and implemented in Europe. According to the implementation over the years and differences between Chinese and Western lifestyles, as well as architectural styles, these regulations were revised many times to adapted to the local elements in Shanghai. In some cases, the regulations were more reasonable than the ones in Europe.

In the early period of the Republic of China, because of the First World War, China's national capital industry developed rapidly. Shanghai soon became the largest city in the Far East. The construction industry had unprecedented prosperity and thus, the gap between Shanghai and the western developed countries narrowed considerably in terms of architectural technology. As for the Broadway Mansions and Park Hotel, which were both built in 1934, *“their completion marks that Shanghai’s modern architectural structure had reached*

*the highest level of the Far East at that time.”*¹ From 1929 to 1938, thirty-one high-rise buildings with more than ten floors were built. By comparison, the first high-rise building built in Beijing in 1951, the Peace Hotel, had only eight floors.

It can be said that due to the introduction of advanced western technology, Shanghai has been a leader in the construction industry within China. In the decades after the founding of the P.R. China, due to social unrest, Shanghai's construction industry steadily slowed, “*Municipal construction had lingered at the stage like building new worker houses, replacing water pipe network, etc.*”² After the Chinese economic reform, the development of urban construction in Shanghai began to restart. In 1992, the 14th National Congress of the Communist Party of China was held. China proposed guidelines to, “*concentrate on the development and opening of the Pudong District of Shanghai.....build Shanghai into an international economic, financial and trade center as soon as possible.*” Since then, Shanghai's urban construction has developed rapidly. The Pudong District has become one of the biggest construction sites in China. Located in Pudong, Lujiazui financial trade zone

¹ Wu Jiang 伍江, *Shanghai bainian jianzhushi: 1840-1949* 上海百年建筑史:1840-1949 [The Centennial History of Architecture in Shanghai: 1840-1949] (Shanghai: Tongji University Press, 1997), 109.

² “上海市,” Wikipedia, <https://zh.wikipedia.org/wiki/上海市>.

is only 1.7 square kilometers. However, in Lujiazui area, nearly fifty high-rise buildings over 100 meters high were built in just twenty years (Figure 1-1). In the center of Lujiazui there are three famous skyscrapers - Jinmao Tower, Shanghai World Financial Center, and Shanghai Tower. Of this trio, each building has qualified as the tallest building in China in succession. Moreover, in the Shanghai Expo in 2010, Shanghai demonstrated many of the latest architectural technologies to the world. The significant evolutions in building, allowed Shanghai's architectural technology to undoubtedly take the lead in China.

Figure 1-1 The comparison of Lujiazui, Shanghai in 1990 and in 2015

Due to the research presented, it can be said that since the founding of the P.R. China, the major period of introduction and development of new architectural technology in China happen after the Chinese economic reform. Specifically, from the early 1990s to now China's economic development experienced a long period of rapid growth. The impact of architectural technology on the architectural detail within China, is bound to be impacted significantly by this era. Except during periods wars and the Cultural Revolution, Shanghai's construction activity has been flourishing since the beginning of the modern age. With an open city culture, Shanghai has become center stage of Chinese architectural technology developments. Moreover, thanks to well-directed preservation within the city, numerous old and new architectural technologies are displayed simultaneously throughout Shanghai. As such, this city provides sufficient elements of analysis to be used as an example for the research of this dissertation. Due to the above reasoning, Shanghai and the period after the Chinese economic reform will be the spatial and temporal scope of this research.

1.3 Concept analysis

1.3.1 Architectural detail

In the context of art, detail is opposite to whole, however, in architecture, they are hard to distinguish. There is no scale standard to define architectural detail, which means that the one larger than a certain scale should be categorized as architecture entirety, or details of smaller scale should be categorized as architectural detail. For example, a window, the pane, the frame, and the size and material are the architectural details of the window. As a whole however, the facade of the building, the dimension or style of the windows, and the other elements such as the parapet or the surface of the wall, relates to the concept of architectural detail, but contributes more to the facade as a whole. Furthermore, in a wider perspective, the facade, and structure system, interior decoration and others alike are the building's details. Hence, architectural detail is a very broad concept, and is almost all-encompassing. It doesn't make sense to say that, "architectural details constitute the building.", because architectural detail does not adequately equate to an entire building component. Consequently, we need to determine the delimitation of architectural detail at the beginning of the research.

In the book, *Architectural Detail Design*, the author Chen Juan points out that

in the context of architecture, the concept of architectural detail entails two attributes; the low-level one is the physical attribute, such as material, structure system and tectonic method. The high-level one is the aesthetic attribute, such as style, color, texture. His implication is that architectural detail needs to meet two kinds of requirements simultaneously - functional and aesthetic. For example, the exterior brick wall is partially buried in the earth to set on the brick foundation. Although the part buried in the soil still belongs to the whole building wall, it is not referred to as architectural detail being that its aesthetic property is not visible, and is more or less unnecessary. Similarly, for the unified visual effect, some sun louvers are set on the building's north facade to correspond with southern ones. Although the louvers are physically the same, unlike the southern ones, the north sun louvers have no functional properties. As a result of this, the sun louvers on the north facade are not considered architectural detail either. On the contrary, the sun louvers on the south facade have both properties of physical function and aesthetic art, and therefore, are referred to as architectural detail.

Above all, in the context of architecture, architectural detail should refer to the building's components which simultaneously have the attributes of physical function and aesthetic art. This is the definition of architectural detail, and also the selection criteria for the objects discussed in this dissertation.

1.3.2 Architectural technology

It is difficult to exactly define “architectural technology” as the result of its broad meaning. In the book “Architecture ABC”, the definition given is, a comprehensive technical means and design method which is related to architectural lighting, heating, facilities and environment, and architectural construction, building energy saving, earthquake prevention, etcetera. This definition is summarized by the various fields of architectural expertise involved and although many fields were mentioned in this definition, they are still a part of the repertoire. Accordingly, modern architectural technology has become a largely encompassing system, in which there are three main aspects: material, design and construction techniques. These techniques are mutually influenced and evolve respectively. From a construction point of view, the content of architectural technology is divided into three areas: material selection, structure design, and construction technique. Undoubtedly, science and technology are the reasons for the development of these areas. The development of one area will lead to the change in other areas, and ultimately promote the evolution of architectural technology.

However, science and technology are not the only influences on the evolution

of architectural technology, as some changes are not necessarily progressive. New laws and regulations, disappearance of traditional craft, economic fluctuations, as well as trends and the other factors can cause hindering short-term or long-term impacts. These impacts can be seen through the changes of material, structure design and construction technique on architectural technology. Arguably, material, structure, and technique are the outward appearance of the architectural technology. In comparison, the advancements in science and technology with the accompanying changes in laws and regulations, traditional craft, and the economy are the intrinsic influences of the evolution of architectural technology. As such, architectural technology impacts architectural art, both on its outward appearance, as well as intrinsically.

1.4 Research explanation

From a performance point of view, there are two modes of the impact caused by the change of architectural technology on architectural art – “rapid” and “gradual”. The cause of “rapid” impacts are often due to the enactment of new laws and regulations. These laws and regulations are often widely and immediately enforced after the promulgation, so their effect on the architecture emerges quickly. While in most cases, the impact is a “gradual”

one, its effect gradually becomes more apparent. As mentioned above, the intrinsic reasons of evolution in architectural technology are craft transition and economic development. The popularity of new architectural technology is often gradual and a long-term process. During this time, the old and new architectural technologies are coexisting. Because of the inertia of the public's aesthetic taste, though the new architectural technology has been applied, the old architectural art will still be dominant for a certain period. For example, Turbinenhalle der AEG in Berlin, designed by Peter Behrens and built in 1909, is well known as the first real “modern architecture”. It was built with a steel structure system, which was the most advanced architectural technology in that time. The corners of the buildings facades were still designed as masonry bearing walls, and do not perform the features of the new structure.

Undoubtedly, change in architectural technology will affect architectural art. As discussed above, changes in architectural technology has influenced the performance of architectural art to some extent. However, many of these technologies are still not mainstream in the current construction market, and their impact on architectural art are often misunderstood through what is actually the architect's personal style. Nevertheless, these impact trends are really essentially related to popularization. This dissertation will continue to discuss research on how architectural technology impacts architectural art,

specifically in architectural detail design. It will also look at how these impacts will lead and affect architectural art in the future.

CHAPTER 2. The Restriction of Architectural Technology to Rationalism

In the Chinese architecture textbook, “Foreign History of Modern Architecture”, “rationalism” is regarded as an ideological design trend, which was formed in an interwar period. Rationalism in architecture is described as a derivative of modern architecture. However, according to architectural philosophy, rationalism ideology has been present in the Western history of architecture since classic architecture. More specifically, Classical rationalism and Gothic rationalism, which were popular in Europe in the 19th century, played a catalytic role in the birth of the "Modern architecture". In the book, *Changing Ideals in Modern Architecture, 1750-1950*, Peter Collins considers Rationalism “as the belief that architectural forms not only required rational justification, but could only be so justified if they derived their laws from science.”¹ Furthermore, he believes that “Rationalism is still, and must always be, the backbone of any valid architectural theory,”² because, as he argues, “however deeply the alliance between architecture and sentiment may be explored, between architecture and science must always be its ultimate

¹ Collins, *Changing Ideals in Modern Architecture*, 198.

² Ibid., 199.

basis of existence.”¹ Peter Collins is essentially saying that Rationalism is the pursuit of the science of architectural technology. The science of architectural technology can be seen in the building's construction; the structure system is in conformity with the mechanical logic, and the characteristic of the material is authentically shown. In other words, the science of architectural technology refers to the authenticity and logicity of the tectonic process. In the 19th century, classic rationalism architects and gothic rationalism architects debated over whether the flat arch is reasonable in structural terms. Moreover, in his speech at the School of Fine Arts in Paris in 1853, Eugene Emmanuel Viollet-le-Duc, a famous French architectural theoretician, said that applying the architectural materials in accordance with their quality and characteristics was one of his own principles of architectural art. This theory shows that structure logicity and material authenticity are the two main aspects of science in architectural technology, and are therefore two of the manifestations of Rationalism within buildings. Thus, the changes of architectural technology can undoubtedly have an effect on both the structure and material, and by extension, make the impact on the performance of Rationalism.

¹ Collins, *Changing Ideals in Modern Architecture*, 199.

2.1 Impact of architectural technology on material authenticity

Material authenticity wasn't considered an issue of architectural ethics until modern times. In the classical age, because of the limitations of craftsmanship and technique, the masonry was the bearing material as well as the surface material for one building. Thus material authenticity was essentially not a matter. Since early modern times, due to the advances in science and technology, as well as the popularization of industrialization, a large number of new architectural materials emerged and were widely used. This greatly enriched the architects' design choices. Nevertheless, the social mainstream values tended to consist of a long-term acceptance period from the old architectural form, which had been "classical", in a period of time where the mainstream social aesthetics lagged behind the development stage of architectural technology. Accordingly, there were the cases that architects simulated the traditional architectural detail with the new material (Figure 2-1). Therefore, material authenticity was gradually taken seriously. For example, after the invention of the reinforced concrete, western rationalism scholars strongly criticized construction made by a new materials with the classical form, because the form was a stone masonry derivative. Those rationalism scholars insisted that the form shall follow the material characteristics, and the characteristics shall be expressed by the tectonic. With the help of the long-

term social development, lagged social aesthetics will catch up with the material authenticity that the rationalists have consistently adhered to. But, because the characteristics of traditional material aren't compatible with higher standards brought by advancements, architectural technology evolution may have a negative effect on the realization of material authenticity.

Figure 2-1 GRC prefabricated column

2.1.1 Forbidding Using Solid Clay Brick

Clay brick is an architectural material that has a long history in China. Although traditional Chinese buildings were mainly built by timber, clay bricks were widely used for city walls, houses, tombs and the other kinds of construction. In ancient China, there were imitation wood components made with bricks (Figure 2-2). After the Opium War of 1840, and since the introduction of advanced machinery by the West, the industrialized

manufacturing of burnt clay bricks began in China. Until the use of new masonry materials such as concrete blocks, and fly ash bricks, clay bricks, especially solid clay bricks, was one of the main building materials in China.

Figure 2-2 Wood-like bracket set made by brick

The clay brick is an old architectural material that comes from nature. The surface texture of this material will naturally give people a sense of intimacy and warmth. Because of its natural attributes, the pristine beauty of this material continues to become more impressionable as the years pass and the wind and rain cause erosion. The "father" of modern Chinese architecture Liang Sicheng, and his wife Lin Huiyin who is also a noted Chinese architect, revealed the source of the brick's timeless beauty in the article, 平郊建筑杂录 (A miscellany of buildings in suburban Beijing). They wrote: *"The little bricks give the building the expression of the earth, the vicissitudes of the history, the vitality of life and the warmth of humanity. This is unattainable for*

*many modern technology and materials.”*¹ Therefore, although new architectural materials emerge endlessly today, brick, especially simple brick, is still a favorite with architects. Simple brick buildings often create architectural beauty just by the brick bonds, without than any additional adornment elements. For the architects that advocate rationalism, because the surface texture is faithfully demonstrated in the brickwork, simple brick building achieves a coherence of form and structure, and therefore achieves “material authenticity”.

In general, one standard brick can be used for three different sizes on a surface of a wall (Figure 2-3). Because of this, brick bond pattern is the main artistic technique of brick walls. In ancient China, the conventional brick bond was the running bond, and sometimes, the course and header bond. With the introduction of modern western architecture technology and style, brick bonds, such as English cross bond, Flemish Bond, became more commonly used in China. The common brick bonds are presented below (Figure 2-4).

¹ Liang, Sicheng 梁思成, and Lin Huiyin 林徽因, *Pingjiao jianzhu zalu* 平郊建筑杂录 [A Miscellany of Buildings in Suburban Beijing], 佛教文化 [The Culture of Buddhism], 0(1).

Figure 2-3 Brick orientation

Source: “Brickwork,” Wikipedia, <https://en.wikipedia.org/wiki/Brick>, (June 12, 2015).

Figure 2-4 Bond patterns

Due to different production processes, clay bricks can present different surface

colors and textures (Figure 2-5). The most common classification, according to cooling methods, is by the color, typically resulting in gray and red bricks. The gray brick and the red brick have almost the same hardness and resistance, however the gray brick is superior in the resistance of oxidation, hydration and weathering. In China, the ancient architecture that has been preserved to present day are almost all gray brick buildings. In the early modern era in Shanghai, the buildings were mostly constructed of gray bricks. However, this change when the influx of western colonizers began. Due to the British colonists' love of British-style buildings, red brick became the building material used in Shanghai during this time. Furthermore, because minerals contained in the soil vary, the color of the brick in different regions is not same. For instance, in the southeast part of China, because the soil is rich in iron, the local sintered brick has the bright red appearance. It can also be seen with black stripes on the surface as a result of the brick stacking method used in the kiln, creating what is referred to as the unique "Rouge brick" (Figure 2-6).

Figure 2-5 Variety of brick color and texture

Figure 2-6 “Rouge brick”

There are various brick bond patterns, colors, and textures, and therefore even if the size of the brick is uniform, each piece used in the building can show unique artistic characteristics.

(1).Laws and regulations for banning solid clay bricks

Although being throughout Chinese history of architecture, using clay bricks can cause the huge soil and energy wastes, which has received unprecedented attention in modern society. As early as 1991, accelerating the innovation of wall materials was proposed in the outline of China's Eighth Five-Year Plan. In next year the Chinese government issued, *“Circular on Accelerating the Reform of Wall Materials and Promoting Energy-saving Buildings.”* In this circular it states, *“At present, 95 percent of wall materials are solid clay bricks in our country. Annual energy consumption of wall material production and building heating is nearly 1.5 tons Tce (ton of standard coal equivalent), which accounts for about 15% of the national total annual energy consumption. Over the country all the brick-tile factories cover an area of about 4,500,000 acres, coal-based power enterprises emit more than 2 tons of fly ash and coal gangue every year. This causes the problem that not only a lot amount of*

arable land is occupied, but also the environment is polluted.”¹ Thus, though clay brick has been a well-liked wall material, restricting the use of clay brick, especially solid clay brick, has become an imperative task for China's construction industry.

In the document, “*Circular on Several Opinions on Promoting Housing Industry Modernization and Improving Housing Quality*”, issued by the State Council in 1999, the Chinese government put forward the ban on using clay bricks for the first time. It was written that, “*coastal cities and the other cities with the scarcity of land resources shall prohibit the use of solid clay brick, and limit the use of other clay products.*”² The following June, the National Building Materials Bureau, Ministry of Construction, Ministry of Agriculture and Ministry of Land and Natural Resources jointly released the “*Circular on the Publication of the List of Large and Medium Sized Cities Designated to Gradually Ban the Use of Solid Clay Brick in Designated Time.*” This is also commonly known as “1st city list of banning”. It required that by the end of

¹ *Guanyu Jiakuai Qiangti Cailiao Gexin He Tuiguang Jieneng Jianzhu Yijian De Tongzhi* 关于加快墙体材料革新和推广节能建筑意见的通知, The State Council The People's Republic of China, <http://www.gov.cn/zhengce/xxgkzl.htm>, (1992).

² *Guanyu Tuijin Zhuzhai Chanye Xiandaihua Tigao Zhuzhai Zhiliang Ruogan Yijian De Tongzhi* 关于推进住宅产业现代化提高住宅质量若干意见的通知, The State Council The People's Republic of China, <http://www.gov.cn/zhengce/xxgkzl.htm>, (1999).

June 2003, 160 large and medium cities, adjusted to 170 cities in 2001, shall prohibit the use of solid clay bricks. Since then, China had formally taken substantial steps in banning building with solid clay brick. Furthermore, in 2004, the five ministries of China have jointly issued, the “*Circular on Further Improving the Work of Banning Solid Clay Brick*”. It further stated that the ban on solid clay brick will gradually be extended to on the other clay products, such as porous clay bricks and hollow clay bricks.

However, compared with new masonry materials, the clay brick still has better performance in fire and moisture proofing, as well as insulation. Moreover, the clay brick has been a favorite material among people for a very long time and therefore, banning the use of clay bricks would be long-term task. In 2005, five years after launching the banning pronouncements, in the “*Circular of the General Office of the State Council on Further promoting the wall materials innovation and extending energy-saving buildings*”, it was pointed out that “*the situation that clay bricks and non-energy-saving buildings prevail predominantly in our country has not changed fundamentally. 70% of construction material is wall material, in which clay brick dominates. For the production of clay brick, the annual consumption of clay resources is more than one billion cubic meters, equivalent to about 500,000 acres of farmland damage. Meantime, the annual production clay brick consumes about*

70,000,000 tons Tce.”¹ In this circular, the State Council put forward a broader and more specific requirement, *“The 170 cities which have banned the production and the using of clay bricks should gradually advance the elimination of clay products, and extend it to the suburb towns.The aim is by the end of 2006, to decrease the national annual production of solid clay bricks by 80 billion, and by the end of 2010, to realize that all the cities ban the use of clay bricks.”*² After, in 2005 and 2009, China also unveiled the second and third list of cities which were designated to follow the prohibition on use of solid clay bricks By the end of 2010, *“except for some cities that don’t have the ability and conditions to prohibit solid clay bricks due to small-scale construction and backward economy, more than 600 cities nationwide have basically prohibited the use of solid clay bricks in the urban area.”*³

Porous clay or hollow clay bricks are thought to be a substitute for solid clay bricks. However, because the firing degree is difficult to control, their final size varies greatly and the quality is poor. Therefore, the structure of a simple

¹ Guowuyuan Bangongting Guanyu Jinyibu Tuijin Qiangti Cailiao Gexin Hetuiguang Jieneng Jianzhu De Tongzhi 国务院办公厅关于进一步推进墙体材料革新和推广节能建筑的通知, The State Council The People’s Republic of China, <http://www.gov.cn/zhengce/xxgkzl.htm>, (2005).

² Ibid.

³ Ibid.

brick building, made by porous clay or hollow clay bricks, is significantly inferior to a building made by solid clay bricks, and thus they are seldom used for constructing decorative exterior walls. Moreover, although porous or hollow clay bricks could reduce the amount of soil resources used compared to the concrete block and other new wall materials, soil is still unavoidably wasted. Since 2011, China's policies that required banning solid clay bricks turned into limiting and prohibiting clay products. "Guidance on Wall Material Innovation during Twelfth Five-year", was issued from China's National Development and Reform Commission. It put forward the goal, that *"by 2015, clay products are limited in more than 30% cities, solid clay bricks are banned in more than 50% counties."*¹ A specific list of related cities this applied to was issued in 2012. However, Shanghai took a leading role within China to restrict the use of clay brick early on. As early as October 2000, four months after, the "1st city list of banning" was released, the Shanghai Municipal Government issued, the *"Interim Measures on the Restriction and Prohibition of Clay Bricks in Shanghai."* It stipulated that all the clay bricks, solid or not, cannot be used in the non-bearing and enclosure walls of construction located within Shanghai's urban area beginning January 1, 2001.

¹ "Shierwu" Qiangti Cailiao Gexin Zhidao Yijian "十二五"墙体材料革新指导意见, The State Council The People's Republic of China, <http://www.gov.cn/zhengce/xxgkzl.htm>.

From the series of laws and regulations mentioned above, it can be seen that clay bricks were completely replaced by other wall materials as a trend of development and under direction of the government. There will be no stage for the simple buildings to show themselves in China.

(2).Advent of faux brick technique

Due to the laws and regulations previously mentioned, solid clay brick is still being phased out in the construction market. However, people still prefer its appearance. Therefore, a decorative material used on an exposed wall – such as a thin brick tile, or a kind of veneer tile, is being widely used to achieve the same visual affect. Thin brick tile is not only in favor of resource conservation, but also meet people’s emotional and aesthetic needs for traditional clay brick walls. Although the tile-like material is still clay, it differs from solid clay brick, in that it is a thin brick used for modern decorative material, rather than for load bearing and adornment functions. By adhering to the exposed wall, it provides a decorative feature, without performing the load-bearing role. Its thickness is only 5 ~ 10mm to demonstrate brick texture (Figure 2-7). The thin brick tiles not only saves soil resources but it also achieves an appearance

similar to traditional Chinese brick buildings.

Figure 2-7 Construction of thin brick tiles detail

As early as the 1930s, veneer tiles were used in Shanghai, China. For example, the Ruijin Hotel (formerly the Morris' villa, Figure 2-8) built in 1924, and the Broadway Mansions (Figure 2-9) built in 1930, both used the veneer tiles manufactured by China's first brickyard – No.1 Plant of Taishan Brick and Tile Co. Ltd. Since the 1980s, veneer tiles have been widely used in China, and their styles have gradually enriched to imitate the various appearances of brick. After the thin brick tile was developed out of the Chinese factory, a wall with veneer tiles could simulate even an age-old, weathered brick wall of the ancient building (Figure 2-10). Entering into the 21st century, because of the laws and regulations of banning solid clay bricks, constructing a new building by clay bricks was impossible. Thus, using thin bricks to simulate brick walls,

especially for a sense of history in the buildings aesthetics, was the main, if not the only, way for architects to achieve this at the time. Although in some details such as the convex corner (Figure 2-11), the thin brick tiles could not be identical with the clay brick, but it could still reproduce the artistic effect of old brick building to the maximum extent.

Figure 2-8 Ruijin Hotel

Figure 2-9 Broadway Mansions

Figure 2-10 Antique imitation tiles

Figure 2-11 Brick tiles at the corner

However, the disadvantages of thin brick tiles were gradually revealed as time passed. Used as the outermost decorative material along walls, the veneer tile was often bonded to the insulation material. Due to its larger density, it was vulnerable to weathering and erosion, and as a result it would fall off from the

exterior wall. Furthermore, the construction quality was often not stable. In June 2015, there was an accident in Xi'an where the veneer tiles that fell from a high-rise caused the death of a boy (Figure 2-12).¹ From then on, many cities in China have restricted and even prohibited the use of veneer tiles. As early as 2000, Shanghai issued, the “*Circular on the Popularization and Application of Exterior Architectural Paint to the Construction Works in Shanghai*”. It says that “*the use of exterior architectural paint should be promoted, the design and the use of veneer tiles should be restricted, and the design and the use of exterior porcelain veneer materials such as mosaic should be prohibited except using in the walls of the bottom floor or the podium.*”² Therefore, the faux-brick paint, which has an appearance comparable with thin brick tiles, gradually became favored.

¹ “*Gaoceng Waiqiang Cizhuan Tuoluo Nanhai Shangxue Lushang Beiza Shenwang* 高层外墙瓷砖脱落 男孩上学路上被砸身亡,” [The Tiles From Falling Off The Outer Walls Killed A Boy On The Way To The School] People's Daily Online, <http://edu.people.com.cn/n/2015/0611/c1053-27139598.html>, (June 11, 2015).

² *Guanyu Zai Benshi Jianshe Gongchengzhong Tuiguang Yingyong Jianzhu Waiqiang Tuliao De Tongzhi* 关于在本市建设工程中推广应用建筑外墙涂料的通知, Shanghaishi Zhufang He Chengxiang Jianshe Guanli Weiyuanhui 上海市住房和城乡建设管理委员会, <http://www.shjjw.gov.cn/gb/node2/>.

Figure 2-12 Thin brick tiles falling off

The faux-brick paint is a kind of architectural paint to imitate the color and texture of brick as the outermost coating of the wall. By being divided into grids after coating, the faux-brick paint presents the effect of brickwork (Figure 2-13). The scientific name of the faux-brick paint is “sand slurry synthetic emulsion architectural coatings”, which have been used on building in China since the 1970s. In 1988, China issued a national standard called the “Sand Slurry Synthetic Emulsion Architectural Coatings” (GB9153-1988). However, the early synthetic emulsion coating had some weaknesses in aspect

such as storage, water-tolerance, and anti-fouling, so it was seldom applied. After more than 40 years of improvement in the mixture, presently faux-brick paints have better performance and can completely replace thin brick tiles. In addition, the ban of clay bricks and the restriction of veneer tiles also promotes the wide application of faux-brick paints.

Figure 2-13 Faux-brick paint

Compared to thin brick tiles, faux-brick paint has many advantages. First, the paint's weight is only a tenth of the tiles. This makes it more suitable for the exterior insulation system. Also, the paint's safety is superior, in that it won't

cause debris to fall from buildings. Additionally, it is more environmentally friendly. Faux-brick paints are better than thin brick tiles in the aspect of details performance as well:

- 1) Faux-brick paints have various colors that can be mixed in according to the design of the architect and can be reproduced without a color difference. In the renovation process of an outer wall, the new and old coating's color can be matched exactly. This is would not be achievable using brick tiles. The repair of tiles and retained tiles are hard to match identically. Even between the tiles produced at the same time, there could be the color difference resulting from aging and weathering.
- 2) In corners of interior spaces, the tiles on one wall are exposed on the side surface. It not only destroys the beauty of details but it also is unlike the authentic effect of brickwork. Even if two tiles with a 45-degree corner cut are spliced together, there will be a gap that is inconsistent with the authentic brickwork appearance (Figure 2-14). Delightfully, faux-brick paints don't have the same drawbacks, and therefore can create more realistic appearances of brick walls.

Figure 2-14 Thin brick tile's fault

- 3) According to the design, faux-brick paints can make the aesthetic appearance of brick decoration, such as brick-curving, very easily. In comparison, cutting the tiles directly is more difficult, and makes it prone to edge failure, and therefore, causes a waste in materials.

Because of the source of raw material for brick no longer adheres to current environmental protection, Chinese traditional clay bricks are being gradually and completely eliminated. With the options of thin brick tiles and faux-brick paints, as well as other modern architectural materials and technology, the aesthetic of brick masonry has proved to still be widely desired by the public.

The cultural, regional and emotional connotations represented by brick buildings are still one of kind and evoke an emotional experience for the public. The use of modern technology, which is consistent with the contemporary background, has helped “regenerate” the brick building. Consequentially, under the opposition between ideal and reality, rationalism architectures have to compromise with the emotional needs of the public over their own pursuit of material authenticity.

2.1.2 Disappearance of brick decorations on parapets

Although new architectural materials, such as concrete blocks and lightweight partition board, are gradually popularized, the type of material currently used for building walls in China is still dominated by bricks. Compared to the stone’s hard processing and timber’s easy corrosion, bricks have better comprehensive performance comparatively. Brick’s shape can be changed through cutting, grinding and carving. Traditional Chinese architecture commonly consists of a timber frame for structure, and therefore, the walls only play a decorative role. Thus, the brick walls are liberated from having to providing support for the structure, and can provide decoration multiple ways – creating patterns with brick is one of them. Usually, brick decoration is not a kind of attached adornment, but an “intrinsic adornment”, which utilizes its

own artistic performance to decorate the building whilst is still an integral part of the wall.

The brick decoration is often used on parapets because the parapet is an important architectural detail. From the joint of exterior wall and roof to the end of the wall, *“it can mostly reflect the structural characteristics of architectural form, and then become the remarkable part of the whole building.”*¹ Moreover, a parapet prevents object from falling from the roof, as well as guides drainage, but it does not play the role in building structure. This allows parapets to be freer in form and stronger in decorative effect. In brick parapets, the mold and outer facing masonry are the commonly used for decoration. Brick mold is the decorative brick detail that utilizes the patterns of the bond and shaping to form the multi-level convex surfaces with various texture and lighting effects (Figure 2-15). Brick molds are often be used at the top and bottom of parapets. In the exterior walls of First National Congress of the Communist Party of China Memorial Building, a brick mold was used on the parapet capping (Figure 2-16). At the entrance of Wu Cangshuo Memorial Hall, located in Pudong, Shanghai, the tops of the parapets are ornamented by

¹ Tongji Daxue Jianzhuxi Jianzhu Sheji Jichu Jiaoyanshi 同济大学建筑系建筑设计基础教研室. *“Jianzhu xingtai sheji jichu 建筑形态设计基础”* (Beijing: China Architecture & Building Press, 1991), 27.

the brick molds with different colors used as a highlight (Figure 2-17). Facing masonry is one way of adding decoration with brickwork, which uses processed bricks to create a variety of decorative patterns on the parapet, or special brick bonds to form a perforation effect (Figure 2-18). Parapets usually are not incorporated into the function of a buildings envelope, and therefore, the perforated facing masonry is very common. For example, the North Building and South Building in Tongji University have perforated facing masonry on the parapets (Figure 2-19).

Figure 2-15 Brick mold

Figure 2-16 First National Congress of the Communist Party of China memorial

Figure 2-17 Wu Cangshuo Memorial Hall

Figure 2-18 Facing masonry

Figure 2-19 North Building in Tongji University

However, as the concrete structure is becoming commonplace in China, disadvantages of brick parapet have gradually emerged. In the systems of masonry-concrete structure and reinforced concrete frame structure, the brick parapet is generally built on reinforced concrete ring beams, frame beams or roof boarding. Brick linear expansion coefficient is about 0.5×10^{-5} , and concrete linear expansion coefficient is about 1×10^{-5} , twice that of brick. As there is a big difference between the expansion coefficients of two, it results in thermal expansion. In the summer the expansive deformation of the beam, or roof boarding, is much larger than that of the brick parapet. This results in a shear force at the joint of the brick and the concrete. When the parapet is unable to withstand this force, it causes horizontal cracks in the bottom of the parapet. These cracks run intermittently along the parapet, and in severe cases they run through the whole parapet (Figure 2-20). This not only disfigure the facades but it also makes rainwater penetrate inside roofing and disables the effectiveness of the insulation material, to even cause interior seepage.

Figure 2-20 The crack in parapet

The prevention measures for cracks include setting a reinforced concrete structural column in the parapet. This protects the structure in that the structural columns divide the one long parapet into several short parapets, so that what would be, one large crack is transformed to many negligible cracks. In, “*Code for design of masonry structures*” (GB50003-2001) issued in 2001, compared with the older version (GBJ3-88) from 1988, included new content about preventing cracks in brick parapet. In the section 6.3.2 (9), it states, “*The parapet wall shall be designed with the structural column. The spacing of the structural column should not be greater than 4m and the structural column shall project up to the top of the parapet wall and monolithically cast with the on-site cast reinforced concrete top.*”¹ It is the first time the requirement was made that a structural column should be built in the parapet. This requirement is still retained in the latest version of the code (GB50003-2011). This means that with the popularization of the concrete structure, preventing horizontal cracks on the parapet has become very important. However, in modern architecture, the structural column always has the same or bigger width than the parapet. The structural column breaks up the brick texture’s continuity on

¹ *Code for design of masonry structures (GB 50003-2001)* (Beijing: China Architecture & Building Press, 2002),

the parapet, and furthermore, as “*the structural column shall project up to the top of the parapet wall*”, the brickwork has to be separated by the structural column. This makes real horizontal bricks unusable in modern architecture.

Moreover, as the result of the development of the construction industry in China, Chinese architecture codes have become stricter. Concrete products have gradually replaced many architectural details that were originally built with bricks. Meanwhile, with the rapid increase of China's building material production capacity in recent years, the cost of the materials, such as steel and concrete, have become a progressively smaller percentage of the total construction cost. This also creates a favorable condition for replacing bricks with concrete. The latest “*Code for seismic design of buildings*” (GB50011-2010) sets the requirement for the height of parapets for the first time. In the section 13.3.5 (9), it is written that, “*The height of masonry parapet wall should not exceed 1m, the measures shall also be taken to prevent collapse during the earthquake.*”¹ The “*National Technical Measures for Design of Civil Construction: Planning Architecture Landscape*” issued in 2009 also stated that “*the parapet wall is given priority to on-site cast reinforced*

¹ *Code for seismic design of buildings (GB 50011-2010)* (Beijing: China Architecture & Building Press, 2010),

concrete.”¹ In addition, according to the Chinese code, when the height exceeds 500mm, the parapet wall should take anchoring measures on the seismic fortification zone. This results in most construction companies’ regulations requiring that on-site reinforced concrete should cast the parapet higher than 500mm.

Due to the brick parapet being subject to growing restrictions and gradually crowded out by concrete, insisting on using authentic brick material to decorate a parapet is becoming more difficult. Because of this the architectural details carelessly designed on parapets, and other monotonous machine-made adornment, such as the GRC decoration components, can be commonly seen now. With the development of architectural technology, the use of authentic material is being faced with increasingly strict codes, and the desire for this authentic use makes the rapid technological advances in material seem helpless. Architects have to give up material authenticity to pursue alternative artificial decorations.

¹ *National Technical Measures for Design of Civil Construction: Planning Architecture Landscape* (Beijing: China Planning Press, 2009), 98.

2.2 Impact of architectural technology on structure logicity

Although rationalism may originate from a classical age, the maturity of rationalism, especially structural rationalism, didn't arise until the second half of the 17th century. At the time, it was thought by Peter Collins that civil engineering and architectural design, two occupations or two disciplines, could be clearly defined. Structural rationalism became a mainstream idea and common school of thought that was widespread among Gothicism, Classicism, and Eclecticism eras. In the 20th century, the frame structure systems made of steel and reinforced concrete became well developed, allowing the supporting members and the enclosure walls can be separated. As the result, the structure members can be visable and used as an aspect of architectural art. During this time period, structural rationalism metamorphoses from technical-centric into an aesthetic form. As Mies said, "*Wherever technology reaches its real fulfillment, it transcends into architecture.*"¹

Structural rationalism architects believe that the form of the building is essentially its structure. They claim that architectural beauty should be

¹ Ludwig Mies van der Rohe mentioned in celebration of the addition of the Institute of Design to Illinois Institute of Technology at the Blackstone Hotel on April 17. "ID Merger Speech," Mies van der Rohe Society, <http://www.miessociety.org/speeches/id-merger-speech/>, (accessed September 21).

embodied from the form of the building's structure, being that the structure logicity is the main aesthetic basis of architectural design. "Structure logicity" means that each component follows the structure mechanics to connect with each other in an efficient way, which is to form a unified and organic whole. This connection should not only meet the needs of the structure, but it also becomes a form of architectural art, or as Peter Collins writes, "*it simply meant limiting aesthetic effects to those which logically followed from the nature of the structural components, and designing those components in accordance with rational criteria.*"¹ The Small Sports Palace, located in Rome and designed by Pier Luigi Nervi, is the perfect embodiment of using structure logicity to express architectural aesthetics (Figure 2-21). The reinforced concrete dome with 59M diameter transfers the load through a lattice beam into a 48M Y-shaped strut support. The Y-shaped struts lean along the tangential direction of the roof edge, to most efficiently relay the roof load to the ground. In building the Small Sports Palace, Nervi realized the importance of unity in structure and art design through a clear structural logic. Moreover, structure logicity is not only reflected in the large-scale structure, buy also in the architectural details. In the case of the Small Sports Palace, all three branches of each Y-shaped struts taper from the joint to the end. This

¹ Peter Collins, *Changing Ideals in Modern Architecture*, 2nd. (Montreal: McGill University Press, 1965), 200.

detailed design is conducive to the stability of the pressure bar, and has the characteristics of the one-way force member (Figure 2-22). In “*Architectural Detail Design*”, Chen Juan believes that the detail of structural joint “*is not only the structural part which should be addressed rationally in the design, but also the main part of the variation in architectural form design.*”¹

Figure 2-21 Small Sports Palace, Rome

¹ Chen Juan 陈鏖, *Jianzhu Xibu Sheji* 建筑细部设计, 66.

Figure 2-22 Y-shaped strut

There is no doubt that the rationale behind structure logicity is based on science and technology. Peter Collins defined structural rationalism by saying, *“more specifically as the belief that architectural forms not only required rational justification, but could only be so justified if they derived their laws from science,”*¹ and quoted Cesar Daly by saying he thought that *“the self-imposed task of the Rationalist School was to reconcile modern architecture*

¹ Collins, *Changing Ideals in Modern Architecture*, 198.

*with modern science and industry.”*¹ It can be concluded that the progress of science and technology is bound to have an impact on the expression of structure logicity. This impact not only takes effect in macro-level of architecture but also in the architectural detail design. The development of science and technology has provided architects more new materials and techniques, as well as more ways to exhibit the creative design of structure logicity. However, this also means that some of the old design is unable adapt to the new science and technology, and eventually can be eliminated by the times.

2.2.1 Forbidding Using Brick Arch Lintel

In “*Code for construction and acceptance of masonry*” (GB50203-98), which was issued in 1998, it is stipulated that when the width of the door or window opening is more than 300mm on a masonry wall, the lintel shall be set. For masonry construction, the lintel is a common architectural component. It is used to bear the various loads above the opening, and also transfers the loads to the wall on both sides. In order for the joint of the masonry wall and the opening to be correct, the lintel is emphatically designed in the view of

¹ Collins, *Changing Ideals in Modern Architecture*, 198.

rationalist architects. Therefore, the brick lintel is often used in the brick building as the result of its practicality and decorative effect.

In traditional Chinese brick buildings, the common types of brick lintels are flat arch (or named Jack arch), and arch (or named relieving discharging arch). The flat arch lintel, as in its name, has a flat profile. It is often composed of only brick soldiers and rowlock course, and is formed into a wedge shape that efficiently uses the compressive strength of the masonry (Figure 2-23). A relieving arch lintel is a curved structure, and its span is commonly longer than the flat arch. Relieving arch lintels have many forms, as such round, segmental and lancet arch (Figure 2-24). Generally speaking, an opening in the brick wall structure may undermine its stability. However, brick arch lintels can span a large area by resolving forces into compressive stresses and, in turn eliminating tensile stresses. It makes for a clever use of the mechanical properties of bricks, and clearly shows its own structural logic. Additionally, the presence of brick lintels breaks the monotony created by bricks neatly arranged in the wall. As Louis Kahn said, “*Brick says to you, ‘I like an Arch.’*”. It is no doubt that brick lintels are important architectural details that turn structural logic into architectural art.

Figure 2-23 Flat arch lintels

Figure 2-24 Relieving arch lintels

However, with the increasing demand for the stability of the structure, the use of brick lintel is decreasing in China. In “*Seismic Design Code for Industrial and Civil Buildings*” (TJ11-78) issued in 1978, Article 41 required, “*When the design intensity is 8, unreinforced brick lintel shall not be used. When the*

design intensity is 9, reinforced concrete lintel shall be used.”¹ According to “*Earthquake Intensity Zoning Map of China*” issued in 1977 (Figure 2-25), the design intensity of the most regions of China was 7 and below. It means that at that time brick lintel can still be used. However, the situation began to change in 1989. In the article 5.3.11 of “*Code of Aseismic Design of Buildings*” (GBJ 11-89), which was issued in that year, it required that “unreinforced brick lintel shall not be used on door or window openings.” This indicates that in the aseismic fortified areas of China, the only form option for the brick lintel is reinforced brick lintel. The reinforced brick lintel is different from the brick lintel mentioned above. It is built the same as the surrounding wall but with steel bars. The reinforced brick lintel often looks no different from normal walls, thus, it is difficult to become an intended architectural decoration. From the 1990 edition of “*Earthquake Intensity Zoning Map of China*” (Figure 2-26), it can be seen that more than half of China are aseismic fortified areas. This greatly limits the usage scope of the brick lintel. Although the 2001 edition of “*Code of Aseismic Design of Buildings*” also prohibited the unreinforced brick lintel used on doors or window openings, new guidance was released that was called “*Seismic ground motion parameter zonation map*

¹ Gongye Yu Minyong Jianzhu Kangzhen Sheji Guifan 工业与民用建筑抗震设计规范 (TJ 11-78), (Beijing: China Architecture & Building Press, 1979), 19.

of China”, which replaced “*Earthquake Intensity Zoning Map of China*”. In it, most areas of China became aseismic fortified areas, with the exception of several sparsely populated areas. Therefore, it further shrank the usage scope of brick lintel. Then in the newest edition of “*Code for Seismic Design of Buildings*” (GB 50011-2010), the article 7.3.10 required that neither reinforced nor unreinforced brick lintel shall not be used on door or window openings, and its corresponding explanation goes so far as to say that the masonry lintel in shall be made of reinforced concrete. Since then, the use of brick lintel has been prohibited in most areas in China.

Figure 2-25 The 1977 edition of “*Earthquake Intensity Zoning Map of China*”

Figure 2-26 The 1990 edition of “*Earthquake Intensity Zoning Map of China*”

In addition, even in the area where the brick lintel can be used, the usage requirements have become more stringent. In 1973, China issued the first design code for masonry structure called “*Design Code for Brick Masonry Structures*” (GBJS-73). Article 30 set the requirement that the span of reinforced brick lintel should not be more than 2m, the span of brick flat arch lintel should not be more than 1.8m. This requirement was continued in the 1988 edition of “*Design Code for Brick Masonry Structures*” (GBJ 3-88). However, in the 2001 edition (GB 50003-2001), the maximum allowable spans of brick lintel were reduced. Article 7.2.1 requires that “*the span of brick*

lintel shall not exceed the following specifications: reinforced brick lintel is 1.5m; brick flat arch lintel is 1.2m.”¹ Compared to the previous requirement, the maximum allowable spans of reinforced brick and brick flat arch lintels were both reduced to 0.5m. Although in the newest edition - (GB 50003-2011), these maximum allowable spans were not reduced again, but the following explanation of the code emphasizes that the reinforced concrete lintel should be used preferentially for masonry structures. The brick arch lintel it is not mentioned in the design codes for brick masonry structures over the years. Given the more stringent requirements on the flat brick arch lintel and the reinforced brick lintel, and considering the strong preference of the reinforced concrete lintel, it is believed that the brick arch lintel will be used less as well.

Overall, the use of the brick lintel is decreasing in China. Today, the appearance of brick lintel can be imitated by the concrete lintel with the faux brick technique. However, in the masonry wall, the structure behind the brick lintel will have to be completely abandoned or transformed into an imitation-style decoration.

¹ *Code for design of masonry structures (GB 50003-2001)* (Beijing: China Architecture & Building Press), 45.

2.2.2 The disappearance of the brick vault

In the history of architecture, the brick vault is a kind of roof structure, which is created by humans to pursue a larger construction span than the beam-and-column structure. The most common types of brick vaults are barrel vault and dome. The brick barrel vault is the simplest form of a brick vault. The bricks of the brick barrel are installed vertically and lean at an angle. The form shapes as a barrel or tunnel and is cut lengthwise in half, as represented in its name (Figure 2-27). The brick dome, which resembles the hollow upper half of a sphere, was the favored choice for large-space masonry coverings before the Industrial Age. In China, the brick barrel vault and brick dome had been used as early as in the catacombs of the Han Dynasty (206 B.C. - 220 A.C.), and had been gradually built above ground after the Wei Jin and Southern & Northern Dynasties (220 A.D. – 589 A.D.). Today there are still many examples of the brick vault in the preserved modern buildings in China, and it has become a distinct roof form unlike the traditional Chinese roof style (Figure 2-28). For examples, Tongji gymnasium, a former machinery workshop located in Tongji University in Shanghai City, was built in 1955 and designed by 吴景祥(Wu Jingxiang). Its mosaic tiled roof is composed of three brick barrel vaults parallel to each other. The architect used the curved surface as the transition between the vaults, creating a wave-form brick roof (Figure

2-29). The Holy Trinity Church in Shanghai, built in 1869, is a simple red brick building, and is also known as the “Red Chapel”. Standing on its porch it can be seen that the ceiling is actually semicircular. Although the outside the roof of the porch cannot be seen as the result of the tall parapet, supposedly it is constructed as a brick dome.

Figure 2-27 Brick barrel vault

Figure 2-28 Brick dome

Figure 2-29 Tongji gymnasium

In recent years, except for in a few new experimental buildings, brick vaults have faded away from Chinese people's view. Since the development of architectural technology and the increasing requirement of building performance, the brick vault structure cannot be adapted with the advancing changes. In the first edition of "*Code for Design of Masonry Structures*" (GBJ 3-88) issued in 1988, there was detailed content and general information about the brick vault in Section 6, Chapter 3. However, in the 2001 edition - (GB 50003-2011), the introduction says that the brick vault is canceled according to the code. The result of this was that even if the architect wanted to design a brick vault there would be no relevant codes to use for guidance. Additionally, there were provisions of the brick vault such as "ring-beams shall be installed at the buildings with brick vault for intensity 6-8" in "*Code*

for Seismic Design of Buildings” (GBJ 11-89), which was issued in 1989. However, in the 2001 edition code there were no provisions of brick vaults. This meant that the brick vault was not adapted to the future development of Chinese society and not be further advocated to build anymore. Although the brick vault takes advantage of brick’s compression resistance capability, compared to the concrete vault, the stability of the brick vault is inferior. A set of experiments on damage has found that the brick arch lintel performs worse than the wooden lintel when testing seismic conditions. Moreover, today with the wide use of reinforced concrete, and the increase of labor cost, in-situ cast reinforced concrete vault has become more economical than brick vault. Hence, although there is no ban on the use of the brick vault, nowadays they are not commonly used due to the increasingly stringent requirements of the building’s seismic performance.

When the material is changed from brick to reinforced concrete, the vault tends to be designed with a small curvature. In many old buildings, it can be seen that the curve of the brick arch or brick vault is often similar to a semicircular (Figure 2-30). In contrast, in the concrete roof, the curve tends to be flat. The roof of the Kimbell Art Museum, for instance, is composed of six concrete barrel vaults set alongside on another, presenting the same cycloidal form (Figure 2-31). The main reason for this difference is the varying

structural bearing capacity of the brick and concrete vault. The load on the vault is divided into horizontal and vertical loads. The smaller rise in arch height results in a better bearing capacity of the vault. This also causes a larger span of the bending member, which could cause structural deformation on the vault. Due to the strong ability to resist deformation, the concrete vault is usually designed to be flat, better for large bearing capacity. For the brick vault, because of its poor ability to resist deformation, it is often shaped like a semicircular to reduce the possibility of deformation in order to satisfy the structural requirements.

Figure 2-30 Brick vault is often closer to semicircle or hemisphere

Figure 2-31 The Kimbell Art Museum in Fort Worth, Texas, designed by Louis I. Kahn

As an architect of Rationalism, Louis Kahn believes that being designed into an arch or vault is an honor for brick. However, today the brick vault is gradually disappearing, and architects may lose the opportunity to create this roof form due to a combination of evolving art and technology.

CHAPTER 3. The Influence of Energy Efficiency Design Standard on Architectural Surface Design

3.1 The development history of Chinese Energy Efficiency Design Standard of buildings

As buildings are home to many human activities, the construction industry accounts for much of the total energy consumption. In China, this proportion has exceeded 30% (Figure 3-1). In the 1970s the oil crisis in western countries led the world to recognize the importance of saving energy due to the importance of economic development within a nation. As a result, the concept of “Energy Efficiency in Buildings” has been developed. The goal is to reduce the amount of energy required to ensure the comfort, health, and safety of the building occupants. The effectiveness of these aspects often depends on the utilization of architectural technology.

Figure 3-1 The amount of building energy consumption and its proportion in total social energy consumption in China by year

Source: “2015 *Jianzhu Baowen Cailiao Hangye Fazhan Xianzhuang Lichen Ji Qushi Fenxi* 2015 建筑保温材料行业发展现状历程及趋势分析” [The development status and trend analysis of the building insulation material industry in 2015], Xinlang Dichan 新浪地产, <http://news.dichan.sina.com.cn/2016/01/07/1158230.html>, (June 30, 2016)

Formulating relevant laws and regulation is an important measure to promote building energy efficiency. Specifically, creating the building energy efficiency design standards that can effectively reduce building energy consumption from the source, preventing another generation of non-energy-efficient buildings. The establishment of China’s energy efficiency design standard system began in the 1980s. Back in January 1986, China's State Council promulgated the “*Interim Regulations on the Management of Energy-saving*”, which puts preliminary requirements on building energy-saving

design. In the sixth chapter it said, *“In the premise of ensuring the reasonable living environment, the building design shall take proper comprehensive measures, such as optimizing building’s shape and orientation, improving building envelopes, selecting low power consumption equipment and making full use of natural light, to reduce the energy consumption of lighting, heating, and cooling.”*¹ In that July, China’s ministry of construction promulgated the *“Regulation of Civil Building Thermal Design”* (JGJ24-86). For the first time, it provided descriptions and explanations on the related concept, data, and calculation methods of building thermal design. It offered a theoretical foundation for China’s first building energy efficiency design standard issued a month later. On January 1st, 1986, China’s ministry of construction published, *“Energy conservation design standard for new heating residential buildings”* (JGJ 26-86). It was China’s first building energy efficiency design standard in China, and thus marks the beginning of China’s energy efficiency design standard system. For this reason, the standard has low requirements, and its effect on building energy saving was limited. In addition, due to various reasons, this standard had not been fully implemented.

¹ *“Jieyue Nengyuan Guanli Zanxing Tiaoli 节约能源管理暂行条例,”* The State Council The People’s Republic of China, <http://www.gov.cn/zhengce/xxgkzl.htm>.

In 1992, China's ministry of construction and the other departments jointly issued the "*Opinions on accelerating the reform of wall materials and popularizing energy-saving buildings*". It put forward a higher goal for and a preliminary work schedule to achieve building energy savings. In April of the next year, China's first energy efficiency design standard for public buildings, "*Energy conservation design standard on building envelope and air conditioning for tourist hotels*" (GB 50189-93), was published. In the following October, the new code for building thermal design, "*Thermal design code for civil buildings*" (GB 50176-93) was introduced. It rezoned China's building thermal design areas. In 1994, the Ministry of Construction established a coordinating group and a dedicated office that specialized in developing the policies of building energy efficiency and promoting the relevant work. In 1995, "*China's Ninth Five-Year Plan and 2010 Project of Building Energy Conservation*" was issued. It proposed a formal plan that outlined building energy saving work in China, dividing it into three stages: "*Compared to the energy consumption level of common design in the locality during 1980 to 1981, the new heating residential buildings decreases the energy consumption by 30% by 1996, it is the first stage; then since 1996, decreases by 30% again relative to the baseline of the first stage, as the second stage; since 2005, decreases by 30% again relative to the baseline of the second stage, as the third stage.*" To achieve the target of the second stage,

from 1996 China's Ministry of Construction promulgated a series of design standards for building energy efficiency targeting 50% energy saving. Firstly, "Energy conservation design standard for new heating residential buildings" was improved by changing its energy efficiency from the original 30% to 50%. The existing standards were only applied to the north of China, and therefore, in 2001 and 2003 Ministry of Construction respectively promulgated the "*Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone*" (JGJ 134-2001), which was applied to the middle of China, and "*Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter Zone*" (JGJ 75-2003) for the south of China. Except for some areas in the southwest, the coverage of the design standards extended to most of China. In addition, aiming for 50% energy savings in public buildings, the "*Design standard for energy efficiency of public buildings*" was also issued in April 2005. However, the series of standards released in 2005, which also was the completion date of the second stage tasks in the original plan, were ineffective in their implementation. China's Ministry of Construction investigated more than 3,000 constructions in process all nationwide in 2005. It was found that of all the construction in the north, only 50% was completed by the standards. In the areas of hot-summer and cold-winter weather, there was less than 20%, and in the hot-summer and warm-winter area it was less than 10%. From 2006 onwards, the

Chinese government scaled up efforts to promote the work of building energy efficiency. In August 2008, the “*Civil Building Energy Efficiency Regulations*” was released. It required the energy-saving design of new buildings was vetted by local urban and rural planning departments. It also stated that the description of the building’s energy efficiency should be included in the construction documents, which are valid only after passing inspection. From then on architects and developers in China began to attach an importance to building energy efficiency. In the nationwide special inspection of building energy savings, conducted in 2010, revealed that the proportion of new construction conducted under the standards was 99.5% at the design stage and 95.4% in the construction stage. Hence, the targeting of 50% energy saving wasn’t met until 2010.

In March 2010, China’s Ministry of Construction published “*Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones*” (JGJ 26-2010) and a new edition of “*Design standard for Energy Efficiency of Residential Buildings in hot summer and cold winter zone.*” (JGJ 134-2010). These new standards raised the energy saving target from 50% to 65%, allowing China’s building energy savings to enter into its third progressive stage. In April 2013, the new edition of “*Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter Zone*”

(JGJ 75-2012) was issued. In February 2015, the new edition of “*Design standard for energy efficiency of public buildings*” (GB 50189-2015) was issued. Moreover, for the areas without applicable design standards, the “*Design Standard for Energy Efficiency of Residential Buildings in Temperate Zone*” was compiled, and are expected to be approved in 2017. Then Chinese energy efficiency design standards will apply to all of China.

For better realization of the energy conservation strategy in China, some areas that experience severe cold weather, such as Beijing City, Tianjin City, Shandong Province, Hebei Province, and Xinjiang Province, began to develop and implement local design standards for 75% energy saving after achieving the target of 65%. Shanghai City has also developed its building energy efficiency design standards. In development of residential buildings, Shanghai municipality promulgated “*Energy Conservation Design Standard for Residential Buildings in Shanghai*” (DG TJ08-205-2000) in 2000, and its replacement (DGJ08-205-2011) in 2011. In looking at public buildings, Shanghai municipality promulgated “the standard of energy efficient design for public buildings” (DGJ 08-107-2004) and its replacements (DGJ 08-107-2012) in 2004 and 2012 respectively. As one of the most important international cities in China, Shanghai’s design standards are slightly stricter than the related national design standards. This is mostly due to the fact that

Shanghai is located in a hot-summer and cold-winter zone. The buildings in this area utilize more cooling energy consumption in summer, than the heating energy in winter. Different from the buildings in northern China that can improve energy efficiency by utilizing insulation techniques and advanced heating systems, the buildings in Shanghai show little improvement in energy efficiency through increasing building insulation. Because of this the buildings in Shanghai, have stricter design standards comparatively.

3.2 Effect of energy efficiency design standards

Building energy consumption is mainly produced by heat transfer of building envelopes, except for a small portion through air heat exchange. In all Chinese energy efficiency design standards, there are the limits on the heat transfer coefficient of the building envelopes such as door and window, exterior walls, and roof (Table 3-1). However, the heat transfer coefficient of the common masonry materials, such as hollow bricks and lightweight block, are not able to meet the requirements of the energy saving design standards for energy efficiency in China. Since the Chinese design standard of building energy efficiency was implemented, the wall insulation system has become an essential architectural technology in the construction of new buildings in China. Wall insulation is a system consisting of fitting high-performance

insulation into walls that are in contact with the outside air. The common forms of wall insulations are exterior and interior wall insulation. External wall insulation mainly involves adding insulation boards into the external walls of the building and then rendering on top of the insulation to finish; internal wall insulation mainly involves attaching insulation to the interior walls of the building. In the early development stage of wall insulation technology in China, interior wall insulation was used more widely than exterior. However, since the beginning of the century, as the result of the development of external wall insulation and the prompting from the government, external wall insulation has generally replaced interior wall insulation, and become the mainstream type of wall insulation technology in China.

Table 3-1 The limits of the thermal performance parameters of building envelope in Severe Cold Zone (A)

Source: *Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones (JGJ 26-2010)* (Beijing: China Architecture & Building Press, 2010), 6.

The most common wall insulation materials in current China are mineral wool, EPS (Expanded Polystyrene) and XPS (Extruded Polystyrene), as well as insulating mortar that can also be used. Regardless of the material, it can be used as insulation as long as it has the proper thickness (Figure 3-2). At the request of 65% energy saving in China, the insulation thickness of high-rise

building in Shanghai has to be more than 100mm. For buildings, the insulation consists of a thick coat which wraps along the entire wall. Additionally, due to the masonry wall being hidden behind the insulation, its characteristics, such as color, texture, and the bond patterns, cannot be used as the decoration of the building. The decorative technique directly on the brick or block, such as brick carving, will also be hidden and therefore, not play the role of wall decoration. Moreover, the decorative details, such as brick molds, are also difficult to use for a desirable effect. In order to prevent the thermal bridge, the insulation material must cover the components made by brick or concrete, which are attached to the exterior wall. With the thickness of the insulation with the plasterwork and finishes, the final size of these details often result larger than size generated only by masonry material. As Figure 3-3 shows, the window casing is generated from the concrete component. With the insulation covering, the component is as thick as, or even thicker than the initial casing. In the masonry building with external wall insulation, the decorative details always have a heavy look, and may result in the aesthetic imbalance. However, if the thickness of the insulation is taken into account early in the detail design stage, the size of the decorative detail components without the insulation can be made smaller. To avoid the situation that the components are too detailed to be constructed by brick or concrete, the architect often has to put the decorative detail in a simple shape design, and this results the decorative detail

losing delicateness. In addition, the design of building energy efficiency in many cases must adopt the comparative judgment method in order for the thickness of the insulation to be accurate. However, this method cannot be used until the building design is finalized. This brings many uncertainties to the detail design. In order to prevent the decorative detail from being enlarged by the insulation, the architect cannot create details, such as mold and window casing, through masonry materials used for constructing walls. However, the architects tend to install the insulation on the flat masonry wall first, then set the decoration members as architectural detail atop the insulation. Therefore, the decorative detail is separated from the masonry wall, no longer a part of it. As a result of this, the material of the detail is gradually transformed into lightweight as opposed to heavy masonry material. Today in China, the more common materials of decoration members are EPS and GRC (Glass fiber Reinforced Concrete).

Figure 3-2 Insulation material needs to have enough thickness to play the role

Figure 3-3 The window casing with the insulation

Source: *Guojia Jianzhu Biaozhun Sheji Tuji: 02J121-1 Waiqiang Waibaowen Jianzhu Gouzao (Yi)* 国家建筑标准设计图集: 02J121-1 外墙外保温建筑构造(一) [National Building Standard Design Atlas: 02J121-1 The Construction Of External Wall Insulation System (I)] (Beijing: China Institute Of Building Standard Design & Research, 2002), B8.

In terms of architectural art, using insulation materials and masonry materials are similar. They are both the tectonic, an activity that utilizes the requisite material of building construction in an artistic way. The biggest benefit of using insulation material to create decorative detail is that it not only solves the problem of thermal bridge, but also allows the architect to accurately control the final sizes of the decorative details early in the design stage. Compare to EPS, the cohesiveness of XPS is poor. Without the mechanical fastener, the XPS insulation is prone to failure, falling off the wall. Furthermore, XPS material is relatively brittle, thus its surface is easily cracked, causing finishing materials to cast off outer coatings. XPS is used more as the insulation in the roof, and EPS is more preferable for the insulation of the wall. Since the EPS material is easily cut, simply shaped detail can be created with EPS material by cutting and spliced at the construction site. In addition, the details with complex shapes can also be prefabricated with EPS material in the factory. Moreover, because EPS is a light material, the details made with it can be affixed to the insulation or masonry wall without a mechanical fastener. As there are many advantages to using EPS, the techniques to make decorative details for the wall has grown into many different applications in China. However, it has also raised public doubts and discussion regarding the quality of housing.

Figure 3-4 EPS insulation boards

EPS is a kind of soft plastic foam and is often used for decoration detail on the exterior year round. Unfortunately, the soft material makes it easy to destroy through accidental collision with hard objects in the process of construction process or daily use (Figure 3-5). For example, in October 2013, workers accidentally stepped on EPS made objects that fell off from the exterior wall during the renovation. This happened during the EPS insulation of Red Star International Plaza, which is located in Kunming city Yunnan province. This caused the owners to challenge and question the quality of construction, and subjectively accusing that it was of faulty construction. Despite the Construction Quality Surveillance and Inspection Center of Yunnan Province

stating that the external wall construction quality of Red Star International Plaza was up to the national and Yunnan province construction quality standards, this incident still caused controversial disturbances among the building design community. In fact, similar kinds of falling accidents, which included EPS insulation and subsequent public questions, occurred many times in China. Moreover, due to the affixing connection methods, the EPS decoration members in the low-quality construction very easily fall off. Furthermore, because of its poor refractory performance, the EPS decoration members that are exposed to outdoor elements pose real fire risks. Hence, out of concern for the shortcomings of EPS material above, in China architects and developers are increasingly avoiding using EPS to make decorative detail on exterior walls.

Figure 3-5 EPS decoration member was damaged

Glass fiber reinforced concrete, also known as GRC, is also a common material for decorative detail on the exterior wall. GRC was originally developed in the 1940's in Russia, but it wasn't until the 1970's that the current form came to widespread use in western countries. In China the research and development work of GRC material started in the mid-70s, and early 80s. Concurrently, the trend of wall reform and of building energy efficiency popularized the GRC use. However, before 2000, China's GRC products were mainly composite wall panels. In the first ten years of 21st century, the European style was very popular in Chinese building market, specifically in the residential building market. Therefore, many decorative details, such as pilasters, and embossed embellishments, were made in Western classical style, and widely used on the façade design of buildings. In the factory the main production technique of prefabricated EPS decoration members is pipelining cutting, which is not suitable for decoration members with a complex shape. However, GRC decoration members benefit from the manufacturing process of casting, changing the proportion of raw materials and adding pigments to create complex shapes and diverse texture. Therefore, in recent years GRC material has become widely used for decorative details in the western classical style (Figure 3-6). Compare to EPS members, GRC members have higher strength and thereby withstand the failures EPS made detail experience.

Moreover, in China's evaluation (graduated) system of burning behavior in building materials, GRC is a Level A incombustible material, meaning that it has good fire performance. However, because the raw material is cement, GRC members are often too heavy to be affixed on insulation or masonry walls like EPS members. Thus, GRC made additions are commonly fixed on the wall by mechanical-linkage; Firstly, the embedded parts or the keels on the masonry walls are installed during the wall construction, then after installation of the insulation, the GRC decoration members are fixed to the embedded parts or the keels with expansion bolts or welding. Although GRC decorative details perform better in stability and security, and have many advantages over EPS decorative details, for the rational architect, EPS decorative details are more likely to be desired. Due to the design standards of building energy efficiency, the insulation becomes a requisite component of the exterior wall. As the EPS decorative detail is made by insulation material, it could be regarded as a kind of artistic construction of insulation, or the result of tectonic. Thus the "legitimacy" of EPS decoration members is justified. GRC decorative details can only be considered as a kind of additional or dispensable component to the exterior wall, both because its raw material not essential to the wall and it has no other function except decoration. Thus, the argument could be made that GRC decoration members may be considered a violation of Rationalism. Furthermore, the expensive cost of

GRC decoration members and the economic interests of developers in China sometimes cause conflict. Consequently, many architects in the pursuit of design quality are not willing to use GRC decoration members as the architectural detail on the external wall in China.

Figure 3-6 GRC decorative components

In the exterior wall insulation system, using masonry material, EPS or GRC to build decorative details can create some undesirable effects in the architectural design. In recent years, a large number of new buildings, except for the ones that target western classical style, have fewer traditional decorative details like molding in the exterior walls. In China today, the architects' main focus in the architectural detail aspect, has gradually shifted from creating the details with unique art and shape to the selection and visual

presentation of façades materials. Consequently, the flattening of façades has become a tendency in the design of the new buildings in China.

3.3 Effect of Building Shape Coefficient

Except for being a guidance recommendation in the first standard titled “*Energy conservation design standard for new heating residential buildings*” (JGJ 26-86), in all the other buildings-energy-efficiency design standards promulgated in China, the limit of building shape coefficient was a compulsory requirement. This meant that architects needed to pay attention to the building shape coefficient as early as the phase of architectural form conception. The definition of “Building Shape Coefficient” has been made in several Chinese buildings-energy-efficiency design standards. Although the specific interpretations are expressed differently, the contents are identical; building shape coefficient is the ratio that the area of the surface which is in contact with the outside air to the volume enclosed by these surface. Building shape coefficient is an important factor for a building’s energy-efficiency because the consumption is mainly generated by heat transport through building envelope; the smaller this surface area, the less the heat gain or loss will through it. A small building shape coefficient implies minimum heat gain or loss, which is very beneficial to building energy conservation. Moreover,

having a small building shape coefficient in the schematic design phase can give the architects greater leeway to design a real energy-saving building in the following phases, allowing for more choices of the building products, such as doors and windows etc. As shown in Tables 3-2, the limit value of heat transfer coefficient of building envelope is cited from “*Design standard for energy efficiency of residential buildings in hot summer and cold winter zone*” (JGJ 134-2010). It reflects that buildings whose shape coefficient is less than or equal to 0.40 can have a building envelope with higher heat transfer coefficient than the ones whose shape coefficient is more than 0.40. The higher limit value of the heat transfer coefficient can expand the selection range of applicable building products. The small building shape coefficient can bring benefits both in buildings energy efficiency and building product selection, thus the implementation and idea is welcomed by developers. However, pursuing low shape coefficient can make the building look characterless, due to few shape changes.

**Table 3-2 The limit value of heat transfer coefficient (K) and the heat inertia index
(D) of each part of building envelope**

Source: *Design standard for energy efficiency of residential buildings in hot summer and cold winter zone (JGJ 134-2010)* (Beijing: China Architecture & Building Press, 2010), 4-5.

Generally speaking, to lessen building shape coefficient, which is the surface area to volume ratio, essentially means to reduce the surface area of the building. Today in China's major cities, a large part of the new constructions are high-rise buildings. For example, in 2003 Shanghai municipal government promulgated "*Technical Regulations of Urban Planning and Management in*

Shanghai”, which encouraged the new residential construction only to be high-rise buildings in the area circled by the inner ring freeway. For high-rise buildings, the area of the elevation accounts for more than 95% of the area of the building surface. It essentially determines the building’s shape coefficient. Moreover, for high-rise buildings, the area of the elevations is approximately equal to the building height and the floor plan perimeter. The height of the building is determined by many factors such as architectural function, structure form, and electromechanical equipment, and thereby has to be decided in the very beginning stages of design. Trying to address these factors in the later stages will result in many difficulties. The floor plan design is the main way to adjust the building shape coefficient for architects. Considering the principle of a constant area, when the floor plan shape is more regular and closer to a geometric figure, its perimeter is smaller. In order to reduce the area of building elevations, the architects often reduce or avoid the irregularities shape and changes in the floor plan design. For example, the bay window was a kind of decorative element that was often previously used in high-rise residential buildings in China. The bay window actually increases the perimeter of the floor plan. In addition, many design standards show the limit value of heat transfer coefficient of bay window is less than that of normal window, about 10%~15%. Hence, architects gradually have become more conservative in the use of bay windows in design. In facing a problem such as

this, architects tend to design the floor plan profile into a geometric figure and restrict the shape changes within the building. This again ultimately leads to flat façade design.

3.4 Architectural “Surface-tendency” Design

Currently in China, as mentioned above, due to the mandatory requirements by the building energy-efficiency design standards, the existence of the exterior wall insulation and building shape coefficient gradually have a far-reaching impacts on the façade design. In Chinese traditional buildings, the texture, color, and pattern of masonry walls often act as the decorative details. However, in the new buildings, the exterior insulation hides these elements because they are fixed to the masonry walls. Furthermore, the requirement of the building shape coefficient greatly limits the shape of building, forcing the façade to be confined in a two-dimensional space. As a result, the form of a building created only by the basic components of the building’s envelope is almost impossible create with satisfactory architectural aesthetics. Thus, to improve the appearance of the building, the architect can focus on using a building skin, which is attached, and acts more independent from the main body of building. Due to continued innovation, architectural skins are becoming more commonly used to create aesthetically pleasing building

facades and express architectural art. It can be said that aside from digital design, new material, and other new architectural technologies, the design standards of building energy efficiency has also promoted the building design towards the direction of surface architecture.

Surface architecture means that the building's surface is the dominant expression of architectural design in the building. In this case, the surface has displaced the volume and space as the main body status of architecture. In the context of contemporary architecture, the architectural surface is often referred to as the outer layer of the building envelope, which mainly serves a decorative function. Prior to the Industrial Revolution, due to the development of architectural technology, the faces of the load-bearing components or masonry walls in the building were usually exposed. The architectural surface was not an isolated concept. From the Industrial Revolution of the 19th century, due to the emergence of new materials such as steel and reinforced concrete, a huge change in the form of building structure was created. The building envelope is separated from the building structure system, thereby eliminating the restrictions of the load-bearing role and becoming an independent part of the building. Under the guidance of modern architecture, "Form Follows Function", volume and space as the architectural elements hold the balance of the design system, however the architectural surface exists

more as an outgrowth of them, with no independent status. In the contemporary, the building skin has gradually developed its own supporting structure system, and becomes less closely related to the building structure. The architectural surface as the entity of “Form” is no longer necessarily a reflection of the interior space or volume as the entity of “Function” in the building. With the emergence of a large number of new decorative materials, the performance of architectural surface has become increasingly diverse, and the supporting technology, more complex. The architectural surface gradually becomes a building component with a complex system. The architectural surface has an equally important position due to space and volume having a dedicated element for expressing architectural art in the building. Therefore, we can see that because of the constant innovations in architectural technology, today architectural surface has finally gained an independent status and significance in building. These innovations include not only those from the interior of the building, such as the evolution of structure and application of new materials, but also from the exterior of the building, such as popularization of new technology. In fact, the process of architectural technology becoming increasingly complex and specialized is also one of deconstructing building as well. As the most intuitive element to artistic expression in the building, an architectural surface with independent status makes it easy to replace space and structure to become the dominant factor in

building design. It essentially could be regarded as architectural “surface-tendency” design. Thus, under the impetus of factors, like building energy efficiency design standards, the building design is very apt to head in the direction of “surface-tendency”. For example, the buildings in the Shanghai World Expo in 2010 contained a large number of pavilions that were spontaneously designed in the way of surface architecture (Figure 3-5).

Figure 3-7 The surface architecture in Shanghai World Expo 2010

From a macro view of architectural history, the surface-tendency in contemporary architectural design may be inevitable way of architecture, and the representation of historical reincarnation. Baroque is an architecture style

popular in the 17th and 18th century in Europe. It partly abandoned the strict architectural order of classical architecture from ancient Greece and Rome, and used a large number of elaborate carvings and rich embellishments to characterize the façades. In addition, the exterior walls were constructed as curved shapes full of dynamic rhythm. In the Baroque architecture, the decorative exterior walls overtake the interior space and structure, create the character of the building. Thus, to a certain extent, Baroque architecture and Surface architecture are similar because they both put the façades, or to say architectural surface, in the dominant position of architectural art. In other words, if evaluating a building based on what Vitruvius had asserted in his book, *Ten Books on Architecture*, then a structure must exhibit the three qualities of “Solid”, “Useful” and “Beautiful”, for Baroque architecture and for Surface architecture it can be said that “Beautiful” is important beyond “Solid” and “Useful”, and becomes the first element of the building. There is a good explanation for this “coincidence” in the architectural history. In the development of architectural surface, the competition between the surface and the volume is a major contradiction. When the new architecture system is under developing, the surface is subordinate to the volume. When the architecture system has reached a plateau, the surface is going to be the center of attention in architectural design and will show a strong trend toward breaking free from the shackles of the volume. Accordingly, the architectural

surface-tendency design today becomes more common. An inflection point may be closing, and the current main structure used and the resulting space forms are already mature and begin to become stagnant. Architects have to push the surface to the center of the architectural design stage. Then, maybe only when a great change takes place in structural forms and the resulting space, can rationalism return back in the relationship between architectural surface, volume, and structure. However, this great change is unlikely to happen in the foreseeable future, and therefore, the current main structure forms may remain unchanged. Hence, with the help of architects, which want to breach the doctrine and standards of modernism, surface architecture is still in the initial stage and can be further developed to spread in the future.

However, because the building's skin becomes an independent component in surface architecture, the relationship of architectural surface and the main body of building behind it turns out to have a weak correlation. Therefore, the details on an architectural surface will have to separate itself from the main body of the building and only serve as the skin of building. At this point, the architectural details are only a kind of decorative symbol for the whole building. As a result, the architectural detail is no longer a necessity of the building and could easily be replaced or removed. This has created conditions for the popularity of minimalist architecture to some extent.

CHAPTER 4. Impetus of Architectural Technology on Minimalist

Architecture

From the beginning of the 1990s, a designing tendency call Minimalism is gradually rising in the architectural field. Minimalism is an artistic style that began in post–World War II Western art. It is most strongly associated with American visual arts in the 1960s and early 1970s. Minimalism is an art genre, *“where the work is set out to expose the essence, essentials or identity of a subject through eliminating all non-essential forms, features or concepts.”*¹ In the architectural field, *“the concept of minimalist architecture is to strip everything down to its essential quality and achieve simplicity. The idea is not completely without ornamentation, but that all parts, details and joinery are considered as reduced to a stage where no one can remove anything further to improve the design.”*² Minimalism derives from the reductive aspects of Modernism. Minimalist architecture is often regarded as the revival of modernist architecture in contemporary times. However, due to different influence of the times and developmental levels of architectural technology,

¹ “Minimalism (visual arts),” Wikipedia, [https://en.wikipedia.org/wiki/Minimalism_\(visual_arts\)](https://en.wikipedia.org/wiki/Minimalism_(visual_arts)), (last modified on 5 February 2016, at 15:02).

² “Minimalism,” Wikipedia, <https://en.wikipedia.org/wiki/Minimalism>, (last modified on 26 September 2016, at 16:24).

modernist and minimalist architecture have different origins in the pursuit of "simplicity". Modernist architecture was born in Europe at the turn of the 20th century. At that time, because of the rapid technological advancement and the modernization of society brought by Second Industrial Revolution, the urbanization in Europe developed very rapidly. It created a new form of architecture, which was adapted to the low construction cost that was urgently needed for large-scale production. "Simplicity" became the response of modernist architecture to meet this demand. Compared to a century ago, today's society has completely different demands for architectural design. Minimalist architecture's pursuit of "simplicity" is more like the demonstration of technological aesthetics. Although, from a formal point of view, minimalist architecture has a very plain and simple appearance without ornamentation, hidden by this appearance is the high-cost construction and well-conceived design. It can be said that minimalist architecture, which seems to be built easily is often supported by technology and precise construction. Thus this also indicates that the wave of minimalist architecture emerging today is largely the result of the progress of architectural technology.

4.1 Vanishing details

The contemporary minimalist architecture usually has a simple form in its

façade. It follows the principle of “less, less and less” to pursue an “almost nothing” state. Therefore, in many minimalist buildings, the architects not only remove all the ornamentation but also try to eliminate the architectural details that are irrelevant to the topic of design. Although architectural details can serve as ornamentation, their existence should be based on physical function. In other words, the striking dissimilarity of architectural details to decoration members lies in the practical assistance in the use of the building. However, due to the progress of architectural technology, many physical functions of the old architectural details are no longer necessary for the new buildings. As such, this lead to the loss of the architectural detail’s existing foundation, resulting in a gradual disappearance of them, and thus, it also promotes the development of Minimalist architecture.

4.1.1 Plinth Wall

Plinth wall has traditionally been seen as an important architectural detail in China. It is explained in detail in almost all Chinese textbooks of building structure. The Plinth wall is the lowest part of the building’s exterior wall, which is thicker in appearance than the wall above. On the surface of the common masonry material such as brick and block, there are usually many small holes allowing the rainwater to infiltrate into these holes and cause

corrosion damage. Extra protection provided by a layer of cement mortar, stone or other materials is needed. This protection layer is coated on the lowest part of the exterior wall thereby forming the plinth wall. It provides extra protection to the exterior wall against rain splash and penetrating dampness (Figure 4-1). Because of the extra layer, the plinth wall often looks different with the other parts of exterior wall above. This allows it to become an important decorative element of the building in China.

Figure 4-1 The brick building with plinth wall

After the promulgation of energy-saving building design standards in China, the insulation material is always attached to the external wall. However, in the performance of polystyrene insulation, which is most commonly used, it will be greatly weakened when it comes into contact with water. A cement mortar

layer is used as a protection, plastered on the insulation, while the decorative material like a coating or veneer tiles is rendered on the cement mortar as the finish. Due to the protection of cement mortar, the plinth wall is no longer needed for the exterior wall. Additionally, the curtain wall technology has been more widely used, so the masonry walls are often hidden behind the architectural surface, no longer directly exposed to the outside. This makes use of the plinth wall seem too redundant. Thus today in China, the plinth walls, which work as the architectural detail, are gradually disappearing from the façade.

4.1.2 “Tiao Mei Zhuan”

“Tiao Mei Zhuan” was a common winding up treatment of waterproofing membrane in China’s early roof waterproofing construction. The literal translation of “Tiao Mei Zhuan” is “eyebrow brick”, which as metaphor that refers to the brick projecting out at least 60mm from the interior surface of the parapet. This brick is used for the fixation of the waterproofing membrane (Figure 4-2). “Tiao Mei Zhuan” was very popular in China as the result of its simple construction – only making the bricks 250mm above the roof project the parapet. In “*Code for construction and acceptance of roofing engineering*” (GB207-83) issued in 1983, “Tiao Mei Zhuan” was classified as one of the

standard methods of waterproofing roof construction. In one building the bricks of “Tiao Mei Zhuan” are combined together as a line running through the whole parapet, causing the “Tiao Mei Zhuan” to form a visual dividing line between the two materials, brick and membrane, thereby enriching the appearance of the parapet. Therefore, “Tiao Mei Zhuan” became an architectural detail (Figure 4-3).

Figure 4-2 “Tiao Mei Zhuan”

Source: Liu, Zhaoru 刘昭如, *Jianzhu Gouzao Sheji Jichu* 建筑构造设计基础 [The Basis of Building Constitution Design] (Beijing: Science Press, 2000).

Figure 4-3 The “Tiao Mei Zhuan” as an architectural detail

However, in “*Technical Codes for Roof Engineering*” (GB50207-94) issued in 1994, the method of “Tiao Mei Zhuan” was removed. The reason written in the explanation of the code was that because construction quality is difficult guarantee, “Tiao Mei Zhuan” can easily causes the cracks in the parapet and furthermore the rain infiltration, it can greatly degrade the performance of insulation on the roof. The alternative method is to create a horizontal indentation in the parapet and fix the waterproofing membrane in the groove (Figure 4-4). In recent years, due to the fact that parapets have gradually changed to be constructed by concrete, it has become more difficult to set a groove in the parapet. Therefore, instead of the groove, the 2012 edition of “*Technical Codes for Roof Engineering*” recommends using a metal plate to fix the waterproofing membrane, as Figure 4-5. As such, “Tiao Mei Zhuan”, as a former architectural detail, has become obsolete.

Figure 4-4 The groove to fix the waterproofing membrane

Source: Yan, Hongliang 颜宏亮, *Jianzhu Gouzao* 建筑构造 [Building Constitution]
(Shanghai: Tongji University Press, 2010).

Figure 4-5 The metal plate to fix the waterproofing membrane

Source: Yan, Hongliang 颜宏亮, *Jianzhu Gouzao* 建筑构造 [Building Constitution]
(Shanghai: Tongji University Press, 2010).

4.2 Pursuit of Purity

The pursuit of “simplicity” trends aims to promote a simple form of minimalist architecture. This means that the material appearance becomes the essential factor of architectural design. The minimalist architects frequently

use only one material for the building appearance on the major part of the façade, and even whole façade in some cases. Therefore simplicity and translucency have become two common and important characteristics of architectural materials in minimalist buildings. Simplicity of the material can provide a pure and uniform appearance for minimalist architecture. Translucency, by its implicit and ambiguous expression, can enrich the architectural experience. Glass is an unusual architectural material that can have the appearance of both purity and uniformity. In the early stage of modern architecture, the glass was often used as an important element in the façade of the building with simple design tendencies. In many world-famous buildings he designed, Mies used transparent glass as the external wall, thereby creating a very simple building form. With the development of architectural technology, architectural glass in appearance has also undergone great changes. Today the glass used on the façade not only retains its pure appearance but it also presents different transparencies through coating technology. As one of the common architectural materials, glass through the related technological advances promotes the prevalence of minimalist architecture.

4.2.1 Semi-tempered Glass

The glass curtain wall seems to be a natural fit with minimalist architecture. As early as the mid-18th century in Europe, the improvement of smelting technology promoted iron as the material for building structures. Some engineers, without the architects' participation, used glass to create the compact architectural form, which didn't contain traditional decorative features (Figure 4-6). After entering the 20th century, as the frame structure of steel or concrete gradually matured, and became possible that the glass walls could replace the masonry wall to work for the building envelope. As a milestone in modern architecture, Fagus Factory built in 1911, first adopted a true glass curtain wall, thereby creating a kind of light and transparent building wall form. The glass curtain wall dissolves the traditional facade style, and transforms the appearance of the building into the simplest form by presenting only one major material. Whether it is from the high-rise designed by Mies in 1950s or Apple retail stores today (Figure 4-7), the use of the visual purity from the glass curtain wall to create simple building forms has become an important design technique for architects.

Figure 4-6 The Crystal Palace, designed by Joseph Paxton

Figure 4-7 Apple Store Glass Cube, New York City

In 1981, the Canton Trade Fair complex located in Guangzhou City was designed with a glass curtain wall on the part of its façade. It was the first time the glass curtain wall technology was used in China. In the early development of China's glass curtain wall technology, according to the foreign experience, the types of the glass used in the curtain wall were mainly tempered glass and semi-tempered glass. Tempered glass and semi-tempered glass are both a kind of strengthened glass. The production process of tempered glass is that heat is applied to the normal glass evenly up to a certain temperature first, and then it's cool down rapidly by cold air. This tempering puts the outer surfaces into compression and inner surfaces through the body of the glass into tension, thereby greatly increasing the strength of the glass. The production process of semi-tempered glass is similar to that of tempered glass, except for the cooling process. The strength of tempered glass is usually more than four times that of normal glass. Semi-tempered glass is not as strong as tempered glass, but its strength is more than twice of the normal one. In addition, the biggest difference between tempered glass and semi-tempered glass is the state of the glass when it is broken. Tempered glass crumbles into small granular chunks without sharp corners, which is less likely to cause injury (Figure 4-8). However, in semi-tempered glass, like normal glass, it splinters into jagged shards. These shards could cling together in the frame and will not easily fall off, but if falling, they can cause severe injury (Figure 4-9).

Figure 4-8 The broken tempered glass

Figure 4-9 The broken semi-tempered glass

In looking at both materials as a curtain wall, tempered glass has a big flaw on its appearance, which is called “Optical Distortion”. The phenomenon of optical distortion is that the reflected image in tempered glass appears obviously distorted (Figure 4-10). In serious cases, the distortion is almost unacceptable and may cause dizziness and giddiness. The reason of this optical distortion in tempered glass is mainly the variations in glass thickness

and flatness. *“During the process of heat treatment, the glass is heated to a point where it begins to move towards a liquid state. The surface undergoes physical changes which can include bends at the trailing edge of the glass (end kink), small (.008”) rises and falls of the surface (roll wave), or even overall bowing of the glass. These shape changes, of course, contribute to creating convex and concave conditions on the glass surface that will distort reflected images. They are intrinsic to the heat treatment process and cannot be eliminated.”*¹ Thus, even though refined construction and exquisite technique, the glass curtain wall with tempered glass may create a sense of chaos due to the optical distortion, and therefore, it is hard to demonstrate a highly pure and uniform appearance. However, because of the different technological process, the shape and surface of semi-tempered glass are more even and flat than those of tempered glass. In semi-tempered glass, the optical distortion is restricted to the lowest level and the reflected image looks very real. Thus, adopting semi-tempered glass for the curtain wall can provide good performance in glass purity, and avoid the attention of people disturbed by the optical distortion.

¹ “Reflected Image Distortion in Architectural Glass,” Vitrum Industries LTD. http://www.vitrum.ca/cms/wp-content/uploads/2013/05/Vitrum-techbulletin_distortion_v-tb-1-a.pdf, (October 3, 2016).

Figure 4-10 The reflected image in tempered glass

However, because of potential safety risks from the sharp fragments cause by breakage, in China the semi-tempered glass is not considered as a type of safety glass. In China, Shanghai City took the lead in banning the use of semi-tempered glass in the curtain wall construction. As early as October 1996, the Shanghai municipal government promulgated “*Provision on the use and installation of safety glass for buildings in Shanghai City*”. In it, Article 5 requires that the glass that is used as architectural material in all components of buildings, such as dropped ceiling or balustrade panels, must be safety glass. In Article 2, the scope of “safety glass” is limited to “semi-tempered glass, laminated glass, wire glass, and insulating glass composed of the above glass.”

Therefore, semi-tempered glass is excluded from the “safety glass” classification, and thereby can’t be used in buildings. In comparison, before 1999 semi-tempered was not defined as “non-safety glass” at the national level, and could be used in building components throughout China except for Shanghai. Even China’s national standards “*Tempered and heat-strengthened glass used in curtain walls*” (GB 17841-1999), for instance, provided the performance requirements of the semi-tempered glass used in the curtain wall. Typically in China, the regulations enacted by Shanghai Municipality usually have a demonstrative effect and signified a development trend. The classification of semi-tempered glass as a “non-safety glass” was soon extended to the whole country. In the year 2003 in China, the National Development and Reform Commission, the Ministry of Construction, the General Administration of Quality Supervision, Inspection and Quarantine and the State Administration for Industry and Commerce jointly issued “*Regulation for building safety glass management*”. In Article 2, the safety glass is specified as “*tempered and laminated glass, as well as the other glass products made of tempered glass or laminated glass in line with current national standards, such as insulating glass.*”¹ This made it official that semi-

¹ *Guanyu Jiakuai Qiangti Cailiao Gexin He Tuiguang Jieneng Jianzhu Yijian De Tongzhi* 关于加快墙体材料革新和推广节能建筑意见的通知, The State Council The People’s Republic of China, <http://www.gov.cn/zhengce/xxgkzl.htm>.

tempered glass was not classified as safety glass. Article 6 is similar to the previous Shanghai's provision stating that the curtain wall is listed as one of the building components that must use safety glass when adopting the glass material. Although the semi-tempered glass has been widely used in the curtain wall, previously there was no report that semi-tempered glass shards fall and wound. Because of "*Regulation for building safety glass management*", the semi-tempered glass could no longer be used in the curtain wall anymore. This happened in the beginning period of the large-scale construction of high-rise buildings in China. Since the limitation of architectural technology, the curtain wall is the only choice for the building envelope of many new high-rises. In a short time, countless curtain walls with distorted, reflected images appeared in China's cities. Because these high-rise buildings are often the visual focus of the located area, the distortion of the reflected images not only destroy the purity typically shown by glass curtain walls but it also has a negative impact on the city's appearance.

Events do not happen as one wishes. Although the construction of the curtain wall in China began to abandon the semi-tempered glass and largely used the semi-tempered glass as safety glass since 2003, the accidents from tempered glass falling and causing injury due to spontaneous glass breakage have happened frequently. Spontaneous glass breakage is a phenomenon that

tempered glass may break without any obvious cause. The cause of the spontaneous breakage can be attributed to the fact that it is four to five times stronger than normal glass, and is highly tightened by the pre-stress on itself. Any minor damage on tempered glass can cause the tension to snap, creating what is referred to as spontaneous breakage. The damage finally causing the spontaneous breakage may be caused by high winds, or building and framing system movement. The weakness can be attributed to the handling and glazing process that then weakens the glass. However, the most common cause is from the nickel sulfide stones within the tempered glass. Because of the use of stainless-steel machinery in the glassmaking and handling process, the nickel sulfide stones are created from the small shavings of stainless steel containing nickel changing structure. Over time the stones grow, and end up in the center tension zone of the tempered glass. *“When that piece of tempered glass is later exposed to varying temperatures in its final installed position, this tiny stone – which can measure from 0,003 to 0.015 of an inch in diameter – may grow in size, and cause the glass to shatter for no apparent reason.”*¹ The biggest problem, however, is that there is no technology which can completely eliminate the possible formation of nickel sulfide stone in the tempered glass.

¹ “Spontaneous Breakage of Glass,” Glass Education Center,
http://educationcenter.ppg.com/glassttopics/spontaneous_breakage.aspx, (October 3, 2016).

Furthermore, since the nickel sulfide stones are very small, it is impossible to detect whether they exist in the glass or not. Although the heat-soaking procedure can reduce the spontaneous breakage incidences, it can't ensure 100 percent elimination of nickel sulfide inclusion and increases cost, cycle time, and scrap rate. Although the tempered glass breaks into small granular chunks without sharp edges and corners, the idea that they won't cause injury has been rejected by a large number of statistics. Falling from the high-rise tens of meters or even hundreds of meters high, when the chunks near the ground they are travelling as fast as a bullet leaving a gun. Therefore, the amount of damage that would be produced by the numerous falling chunks after spontaneous breakage is needless to say. Currently, the spontaneous breakage probability of tempered glass is about 5 in 1,000. However, for the large cities in China with glass curtain walls spread around, such as Shanghai, this probability would not be low due to the fact that a glass curtain wall on one high-rise can include hundreds or even thousands of glass panels. The frequent occurrence of tempered glass spontaneous breakage in recent years has become a major threat to the citizens' safety. Additionally, even an injury does not result after spontaneous breakage, the replacement of the glass panel in the curtain wall for the high-rise is a very expensive and laborious, which is less affordable for some owners.

Compared to tempered glass, semi-tempered glass has smaller pre-stress, so it rarely spontaneously breaks. Additionally, semi-tempered glass, which won't distort reflected images could ensure the pure and beautiful appearance of a glass curtain wall. Semi-tempered glass is about two times stronger than normal glass. Though not as good as tempered glass, it is adequate for the safety of the building envelope. As one another city full of high-rise buildings, Hong Kong has its own building code system, which is very different from the one in mainland China. In Hong Kong, the glass curtain wall is constantly inclined to adopt semi-tempered glass. Thus, there was a groundswell of support for the re-permission of semi-tempered glass used in glass curtain wall in previous years in China. Faced with this, Shanghai City, once again was at the forefront of China, releasing a semi-tempered glass outline in 2012. According to the 2012 edition of the *“Provision on the use and installation of safety glass for buildings in Shanghai City”*, in Article 5, the curtain wall no longer has to adopt safety glass. This reduces the threat posed by spontaneous glass breakage in Shanghai City. More importantly, as the return of semi-tempered glass, the performances of purity from the minimalist building style in adopting glass curtain wall will no longer be influenced by the optical distortion.

4.2.2 Coated Glass

Truly demonstrating the construction of the building is one basic concept of modern architecture. For the maximum effect, the use of transparent glass in the large area of façade is one of the typical characteristics of the modern architecture. However, through the revival of modernist architecture in contemporary times, minimalist architecture pursues concise and simple architectural form. It is essentially always trying to hide the building's information shown by the façade as much as possible. Therefore, minimalist architecture rarely uses highly transparent glass in a large area of, or around the whole building envelope. The high transparency is almost like concealing the presence of the exterior walls and exposing the interior building materials and structure to the outside. This is contrary to the essence of “minimal”. Nevertheless, the glass is still one of the minimalist architects' favorite materials, because “*the movement of natural light in buildings reveals simple and clean spaces,*”¹ almost all of the minimalist architects identify with the importance of natural light. Thus compared to modernist architects who pay more attention to the transparency of glass, minimalist architects tend to only focus on light transmittance.

¹ Bertoni, Franco, *Minimalist Architecture*, edited by Franco Cantini, translated from the Italian by Lucinda Byatt and from the Spanish by Paul Hammond. Basel (Boston, and Berlin: Birkhäuser, 2002), 15-16.

In the early period of modern architecture, the glass adopted in the curtain wall was only highly transparent glass, such as in Fagus Factory or Bauhaus Building. These buildings laid the foundation of modern architecture styles. Mies first raised the concept of combining window and wall into one, which is entirely generated from the standpoint of architectural art. Because transparent glass doesn't have the strong shadow, it can help the building facade have the most concise form. However, this could no doubt reduce the practicality of the building. The best example is The Farnsworth House designed by Mies. Although a private residence project is typically focused privacy protection, for achieving the idea of "crystal building" Mies insisted on the use of transparent glass as the exterior wall (Figure 4-11). Unfortunately, this resulted in the lawsuit of Edith Farnsworth, the house owner. The major allegation, except the high cost of \$74,000 including the cost overrun of \$15,600, was the poor energy efficiency of the building as the result of all-glass exterior walls. However, Mies' further creations didn't seem to be affected by this lawsuit. He still used all-glass walls in the design of Crown Hall at Illinois Institute of Technology. However, the barely shaded transparent walls cause the interior to be very hot from the direct sunlight in summer and very cold in winter. This causes the usage of the building to be very low, as the students are not willing to stay in an uncomfortable indoor

environment.

Figure 4-11 The Farnsworth House, Plano, Illinois

It is certain that Mies should have predicted these results when he decided to use glass wall as the building envelope. It is well known that the thermal insulation performance of transparent glass is very poor. For example, the heat transfer coefficient of the common 12mm thick flat glass is about $5.5 \text{ W}/(\text{m}^2 \cdot \text{K})$, and of one-brick-thick wall is only about $1.72 \text{ W}/(\text{m}^2 \cdot \text{K})$, less than one-third of the former. The issue of how to improve the thermal performance of the glass wall has been an important task for early modernist architects. In 1958, the Seagram Building designed by Mies and Philip Johnson at New

York City was completed. In its curtain wall, Mies used the tinted glass, specifically the bronze and dark ones, which was just invented soon at the time. Tinted glass is produced by a small addition (typically less than 1%) of other metal oxides. These small additions do not affect the basic physical properties of the glass, only the color and further solar energy transmittance. Although the tinted glass has the same thermal conductivity as normal glass, the advantage of using tinted glass is to minimize infrared transmission with minimum reduction in the visible light spectrum, which means to avoid the indoor high temperature caused by direct sunlight. This technique undoubtedly improved the comfortableness of the building. A greater improvement to glass came in completion of the Bell Labs Holmdel Complex designed by Eero Saarinen in 1962. In its six-story-high glass wall, it was the first time that the coated glass was used in the large-area of the curtain wall. Coated glass, also known as reflective glass, has been treated with a metallic coating commonly on one side to allow it to reflect heat and thereby enhancing the thermal insulation performance. Coated glass is usually combined with normal glass into the insulating glass whose heat transfer coefficient is only about $1.5 \text{ W}/(\text{m}^2 \cdot \text{K})$. This enables the glass curtain wall to have good energy savings performance. Additionally, another important feature of coated glass is it works as a one-way mirror. As the metallic coating is applied to only one side of the glass, the coated glass is partially reflective and partially

transparent. When one side of the coated glass is brightly lit and the other is dark, people can only see through the glass from the darkened side but not vice versa. Thus in the daytime, the coated glass in a curtain wall is like a huge mirror, the people outside can't see the interior of the building, instead, the people behind the glass can see out. Consequently, the glass curtain wall with coated glass is an ideal wall form for minimalist architects. This type of glass does not focus on the transparency but rather light transmittance. Besides being able to provide purity to the façade, coated glass can hide the information within the building to the outside, and at the same time create a natural interior light environment. The John Hancock Tower, which is located in Boston and designed by I. M. Pei, is also a building in minimalist skyscraper design. It was by far the largest possible use of coated glass. The appearance of the building is like a huge mirror that presents an extremely pure effect (Figure 4-12), thereby causing a sensation throughout the American architecture industry at the time.

Figure 4-12 John Hancock Tower, Boston

China's research and production of coated glass began in the 1970s. However, due to limited market demand, the coated glass output was very small by the early 1980s. In March 1985, China's State Council issued the policy that made the processed flat glass products, such as tempered glass and coated glass, as an important development direction of the future architectural technology in China. From the middle of the 1980s, China began to introduce production facilities and technologies of coated glass from abroad, while concurrently increasing the related research. By the early 1990s, thanks to the rapid

development of China's economy, the Chinese domestic demand for coated glass had been improved and domestic coated glass also began to come on the market. China's coated glass industry has since experienced an upward supply and demand, but frustration followed. Due to the technology content of the domestic coated glass being low, in many big cities in China, the problem of light pollution caused by the glass curtain wall appeared. This resulted in many policies restricting use of coated glass and curtain walls. For example, in *“Notice on the Use of Curtain Wall Glass in Construction Projects”*, which was promulgated in 1998 and abolished in 2012 by Shanghai municipal government, it was written to *“prohibit the design and use of glass curtain wall in the construction projects in the area circled by the inner ring viaduct, except for on the podium”*¹ and *“the area of glass curtain wall shall not exceed 40% of the external walls (including windows) in the construction projects in the area circled by the outer ring viaduct.”*² In the same year, Guangzhou municipal government also introduced the relevant provision, which made a series of requirements for the production and use of coated glass used as the curtain wall. These policies had a negative effect on Chinese

¹ *Guanyu Zai Jianshe Gongchengzhong Shiyong Muqiang Boli Youguan Guiding De Tongzhi* 关于在建设工程中使用幕墙玻璃有关规定的通知, Shanghaishi Zhufang He Chengxiang Jianshe Guanli Weiyuanhui 上海市住房和城乡建设管理委员会, <http://www.shjjw.gov.cn/gb/node2/>, (October 20, 2016).

² Ibid.

coated glass market, which was booming at that time, but it also promoted its industrial upgrading. China's tenth five-year plans for the building materials industry and for the glass industry, which were published in 2001 and 2002 respectively, both mentioned that the country should persist in the development of the coated glass industry.

Entering the 21st century, the promulgation of building energy efficiency design standards for 50% energy saving, especially in the public buildings energy efficiency design standards, had given a huge boost to the widespread use of coated glass. Except for the heat transfer coefficient, the 2005 edition of *“Design standard for energy efficiency of public buildings”* also put forward the requirement to limit the value of the external window's shading coefficient. In a building located in Shanghai, for instance, the general shading coefficient of the glass curtain wall shall be lower than 0.40. In the 2015 edition of this standard, the requirement of the shading coefficient was changed to solar heat gain coefficient, but by conversion factors between these two coefficients, it can be found that the limit value of the shading coefficient on the glass curtain wall is even less than 0.25. Thus, for the glass curtain wall without an external shading member, which is most common in China, the coated glass and its composition of insulating glass are the only viable options for the glass material selection. As the result, the coated glass obtained fast

popularization and application in recent years in China (Figure 4-13). Therefore, because the glass curtain wall with coated glass is involved in a large number of the new high-rises, and tends to present the effect of purity, the minimalism style continues to be very popular in the curtain wall buildings in China.

Figure 4-13 The coated glass curtain wall

CHAPTER 5.Summary

It is generally accepted that in the process of designing a building facade, architects will always follow the order of "style first, then details", which means the architects firstly decides the architectural style, then designs the architectural details accordingly. But as described in the first chapter of this dissertation, architectural technology has led to the formation of architectural detail, and architectural style has emerged from the detail. Therefore, architectural technology will inevitably affect the generation and dissemination of architectural styles through architectural details. This effect may play a positive role, but also has its draw backs. Nevertheless, as the decision maker to the building design, architects often do not notice the impact of this effect on their design. It is because this effect is rarely critical, and more commonly is produced by tendency, a predisposition of the architects to create a certain architectural style. Conversely, architects always believe that the selection of architectural style is determined by their own subjective consciousness. However, architectural technology is the foundation of the realization of architectural art. Architectural history has repeatedly shown that the emergence of landmark architectural styles or forms is dependent on the change of architectural technology. Without the support from architectural technology, new architectural style won't have a long-term vitality, becoming

more of a temporary trend only relying on the subjective wishes of the architects.

After the reform and opening up in 1979, China ended its “closed door” state, and began to keep pace with the world’s economy. The architects in China also began to follow the trends around the world, to learn or imitate foreign architectural design. China’s architectural technology has made significant developments in the past thirty years. Due to its rapid development, the role of architectural technology and the evolution of architectural art in China can be more clearly reflected.

For rationalist architects, displaying the science of the architectural technology is the most important of the design principles. Structure logicity and material authenticity are the main two aspects of the science of architectural technology. Early in China’s reform and opening up, due to the social and economic development level, the governmental determined limits on the building envelope and structural system were generous at that time. As a result, many styles of architectural details and components could be constructed and presented as architectural art in building. However, the development of architectural technology has increased complexity, and thereby more restrictions were added on to the building’s constituent system.

Many architectural details, which could be exhibited authentically before, were eliminated or hidden as they were determined to be no longer suitable to be shown. For rationalist architects, in ensuring architectural authenticity, it makes it increasingly difficult to design an ideal work. The rationalist architecture has become more restricted by architectural technology development.

Because in recent years, the construction of buildings in China is astonishing, Chinese architects have been too busy to look for the new design methods of rationalism which can adapt to the new architectural technologies. Under the restriction of the negative factors above, Chinese architects turn to a more effective way to expression architectural art. In the mid-1980s, China began to establish its own design standard system of building energy efficiency, and has promulgated a number of relevant design standards. As an essential element of building energy efficiency, wall insulation technology has been developed from the interior wall insulation system in early time, to the exterior wall insulation system that almost monopolizes the Chinese building market today. For a new way of building, the modern insulation separated the decorative elements from the main body of the building. It allowed the decorative elements, which previously composed the building skin, to form a separate part. Because of this it is very difficult to have the masonry wall

participate in the design of the building façade. Additionally, because of the requirement of the building shape coefficient in building energy efficiency design standards, the changes in building shape have also been greatly restricted. With the emergence and development of the other new architectural technologies such as the parametric design and 3D printing, the architects' modeling ability of architectural surfaces have achieved unprecedented progress. Architects have gradually put more attention on creating new and novel building skins, allowing surface architecture to become popular. Furthermore, the popularity of surface architecture also contributed to architects' tendency towards minimalism. In order to reduce the amount of the decorative elements to the minimum, minimalist architects often adopt the similar design method of surface architecture. It includes hiding the masonry wall, which can reflect much building information, and constructing an architectural surface with a simple and pure form as the building façade. However, the realization of simplicity and purity in architectural surface often needs support from significant architectural technology. With the rapid development of architectural technology in the recent ten years in China, many formerly common architectural details, such as the plinth wall and "Tiao Mei Zhuan", gradually have disappeared due to lack of necessity. New architectural technologies, for example coated glass curtain walls, can create a more concise effect on the building skin. As a result, the design and

construction difficulty of minimalist architecture has gradually been reduced. With the development of architectural technology in China and the emergence of international architectural minimalism wave, it is certain that the buildings with minimalist style will become increasingly commonplace in China.

As the end of this dissertation, the author wants to reemphasize that in only thirty years China's architectural technology has had swift and forceful development, but unless by the laws or regulations are in place, for example, those with national coercive power, the influence of architectural technology on architectural art is always a gradual process, and the trends of architectural style take time to become apparent. In the time after the emergence of new technology, old and new construction technology always coexist. The architectural art begins to show diversity, despite the law of historical development being that that the new things always replace the old ones. Although new architectural technology has not become mainstream, its resulting change in architectural art may not have yet been popularized, but the trend it generates is real and pointed in a positive direction. Thus the content discussed in this dissertation, which is about the impact of architectural technology on architectural art from the reform and opening up to the present, can be considered as part of the discussion about the trends in China's current architecture field. Furthermore, the prediction of Chinese

architectural art perspectives made are also based on the developments of these trends.

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